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Radian Corp., Austin, TX

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PREVENTION REFERENCE MANUAL: CHEMICAL SPECIFIC
VOLUME 2: CONTROL OF ACCIDENTAL RELEASES OF CHLORINE (SCAQMD)

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16. ABSTRACT The manual discusses reducing the risk associated with an accidental release of chlorine. It identifies some of the potential causes of accidental releases that apply to the processes that use chlorine. It also identifies examples of potential causes, as well as measures that may be taken to reduce the accidental release risk. Such measures include recommendations on: plant design practices; prevention, protection, and mitigation technologies; and operation and maintenance practices. It provides conceptual cost estimates of possible prevention, protection, and mitigation measures. Chlorine is a highly reactive and corrosive liquid that boils at room temperature. It has an IDLH (immediately dangerous to life and health) concentration of 25 ppm, which makes it a substantial acute toxic hazard. Accidental releases of toxic chemicals at Bhopal and Chernobyl have increased public awareness of toxic release problems. As a result of other, perhaps less dramatic incidents in the past, portions of the chemical industry were aware of this problem long before these events. These same portions of the industry have made advances in this area. Interest in reducing the probability and consequences of accidental toxic chemical releases that might harm workers within a process facility and people in the surrounding community prompted this series of manuals.

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Chlorine	Storage	Stationary Sources	07B 15E
Disinfection	Materials Handling	Accidental Releases	06F, 06I
Prevention	Maintenance		14G
Accidents	Bleaching Agents		13L 11G
Toxicity	Packaging		06T 13D

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ABSTRACT

The South Coast Air Quality Management District (SCAQMD) of Southern California has considered a strategy for reducing the risk of a major accidental air release of toxic chemicals. The strategy includes monitoring the storage, handling, and use of certain chemicals and providing guidance to industry and communities. This manual summarizes technical information to assist in identifying and controlling the release hazards specific to the SCAQMD associated with chlorine.

Chlorine has an IDLH (Immediately Dangerous to Life and Health) concentration of 25 ppm makes it a substantial acute toxic hazard. To reduce the risk associated with an accidental release of chlorine, some of the potential causes of accidental releases that apply to the processes that use chlorine in the SCAQMD must be identified. Examples of potential causes are given, along with specific measures that may be taken to reduce the accidental release risk. Such measures include recommendations on plant design practices, prevention, protection and mitigation technologies, and operation and maintenance practices. Conceptual cost estimates of possible prevention, protection, and mitigation measures are provided.

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SECTION 1
INTRODUCTION

1.1 BACKGROUND

Recognizing the risk associated with accidental releases of air toxics in southern California, the South Coast Air Quality Management District (SCAQMD), conducted a study in 1985 to determine the presence, quantities, and uses of hazardous chemicals in the SCAQMD, which comprises Los Angeles, Orange, San Bernadino, and Riverside Counties. The SCAQMD study resulted in the "South Coast Air Basin Accidental Toxic Air Emissions Study," a report that outlined an overall strategy for reducing the potential for a major toxic chemical release incident.

The strategy includes: monitoring industry activities associated with the storage, handling, and use of certain chemicals; using the best technical information available; and helping industry and communities minimize the potential for accidental releases and the consequences of any releases that might occur.

Although it appears there have been no significant releases of chlorine in the SCAQMD, chlorine releases have occurred elsewhere. Between 1950 and 1976, 16 reported major chlorine releases caused a total of twelve fatalities and at least 633 injuries. The largest release occurred in 1967 in Newton, Alabama, when a rail tank car was punctured in a wreck. Over 50 tons of chlorine escaped, but no deaths occurred. The release with the highest fatalities occurred in 1952 in Wilson, West Germany, when a boiler that had been converted into a chlorine storage tank failed. Approximately 15 tons of chlorine escaped, killing seven people (1).

1.2 PURPOSE OF THIS MANUAL

This manual compiles technical information on chlorine and on the prevention of accidental releases of chlorine. It addresses issues relating to release prevention associated with the storage, handling, and process operations involving chlorine as it is used in the SCAQMD.

This manual is not intended to be a specification manual, and in fact refers the reader to technical manuals and other sources for more complete information on the topics discussed. Other sources include manufacturers and distributors of chlorine and technical literature on design, operation, and loss prevention in facilities handling toxic chemicals.

1.3 USES OF CHLORINE

Chlorine (Cl_2) is one of the major commodity chemicals used in industry. It is co-produced electrolytically with sodium hydroxide (caustic soda) from sodium chloride brine in specially designed cells. The major industrial uses of chlorine include chemical synthesis of chlorinated chemicals, cooling tower water treatment, and disinfection of drinking water and wastewater. Numerous references in the technical literature provide information on both the manufacture and uses of chlorine. While chlorine does not seem to be manufactured in the SCAQMD, its uses there are typical and require the storage of large quantities of the chemical.

Limited survey data indicate that the predominant uses of chlorine in the SCAQMD are (2):

- Cooling tower water treatment;
- Bleach manufacture;
- Chemical synthesis;

- Repackaging;
- Drinking water treatment; and
- Wastewater disinfection.

The major cooling tower water treatment use is in oil refineries and chemical plants. Municipal or county wastewater disinfection and drinking water treatment are similar applications. General chemical synthesis includes the manufacture of a variety of chlorinated and fluorochlorocarbon products. Other chemical manufacture involves household bleach products. Finally, there appears to be some repackaging of chlorine from bulk quantities into smaller cylinders.

In the SCAQMD, chlorine is stored in small cylinders, one-ton cylinders, railroad tank cars used for stationary storage, and bulk storage tanks.

1.4 ORGANIZATION OF THE MANUAL

Following the introductory section, the remainder of this manual presents technical information on specific hazards and categories of hazards and their control as they relate to chlorine.

Section 2 discusses physical, chemical, and toxicological properties of chlorine. Section 3 describes the types of facilities that use chlorine in the SCAQMD and the process hazards associated with these facilities. Hazard prevention and control are discussed in Section 4, as are the costs of example storage and process facilities reflecting different levels of control through alternative systems. The examples are for illustration only and do not necessarily represent a satisfactory alternative control option in all cases. Section 5 lists references. Appendix A is a glossary of key technical terms that might not be familiar to all users of the manual, and Appendix B presents selected conversion factors between metric (SI) and English measurement units.

SECTION 2
CHEMICAL CHARACTERISTICS

This section of the report describes the physical, chemical and toxicological properties of chlorine as they relate to accidental release hazards.

2.1 PHYSICAL PROPERTIES

Chlorine is an elemental chemical that exists as a gas at ambient conditions but liquifies at moderate pressures. Some of its common physical properties are listed in Table 2-1.

Chlorine is slightly water soluble. The yellow-green gas has a strong, characteristic odor. Because chlorine gas is about 2.5 times more dense than air, it tends to stay close to the ground when released into the atmosphere. Liquid chlorine is clear amber in color; one volume of liquid can vaporize to about 460 volumes of gas.

Liquid chlorine has a large coefficient of thermal expansion, as shown in Figure 2-1. As a result, liquid-full equipment can pose a special hazard. A liquid-full vessel is a full vessel that is not vented and that has little or no vapor space above the liquid. A liquid-full line is a section of pipe sealed off at both ends and full of liquid chlorine, with little or no vapor space. In such cases, there is no room for thermal expansion of the liquid, and temperature increases can result in containment failure.

2.2 CHEMICAL PROPERTIES AND REACTIVITY

Chlorine is neither explosive nor flammable in the normal sense. However, chlorine is an oxidizer which will, like oxygen,

TABLE 2-1. PHYSICAL PROPERTIES OF CHLORINE

		Reference
CAS Registry Number	07782-50-5	
Chemical Formula	Cl_2	
Molecular Weight	70.914	
Normal Boiling Point	-29.3 °F @ 14.7 psia	3
Melting Point	-149.8 °F	3
Liquid Specific Gravity (H_2O = 1)	1.41 @ 68 °F	4
Vapor Specific Gravity (air = 1)	2.5 @ 68 °F	4
Vapor Pressure	85.6 psia @ 60 °F	5
Vapor Pressure Equation		6

$$\log Pv = A - \frac{B}{T+C}$$

where: Pv = vapor pressure, mmHg
T = temperature, °C
A = 6.93790, a constant
B = 861.34, a constant
C = 246.33, a constant

Liquid Viscosity	0.345 centipoise	4
Solubility in Water	6.08 lb/100 gal @ 68 °F and 14.7 psia	4
Specific Heat at Constant Volume (Vapor)	0.085 Btu/(lb-°F) @ 59 °F	4
Specific Heat at Constant Pressure (Vapor)	0.115 Btu/(lb-°F) @ 59 °F	4
Specific Heat at Constant Pressure (Liquid)	0.226 Btu/(lb-°F)	4

(Continued)

TABLE 2-1 (Continued)

		Reference
Latent Heat of Vaporization	123.8 Btu/lb @ -29.3 °F	4
Liquid Surface Tension	25.4 dynes/cm @ -22 °F	7
Average Coefficient of Thermal Expansion, 0-60 °F	0.0011/°F	5
Additional properties useful in determining other properties from physical property correlations:		
Critical Temperature	291.2 °F	4
Critical Pressure	1118.36 psia	4
Critical Density	35.77 lb/ft^3	7
Energy of Molecular Interaction	357 K	8
Effective Molecular Diameter	4.115 Angstroms	8

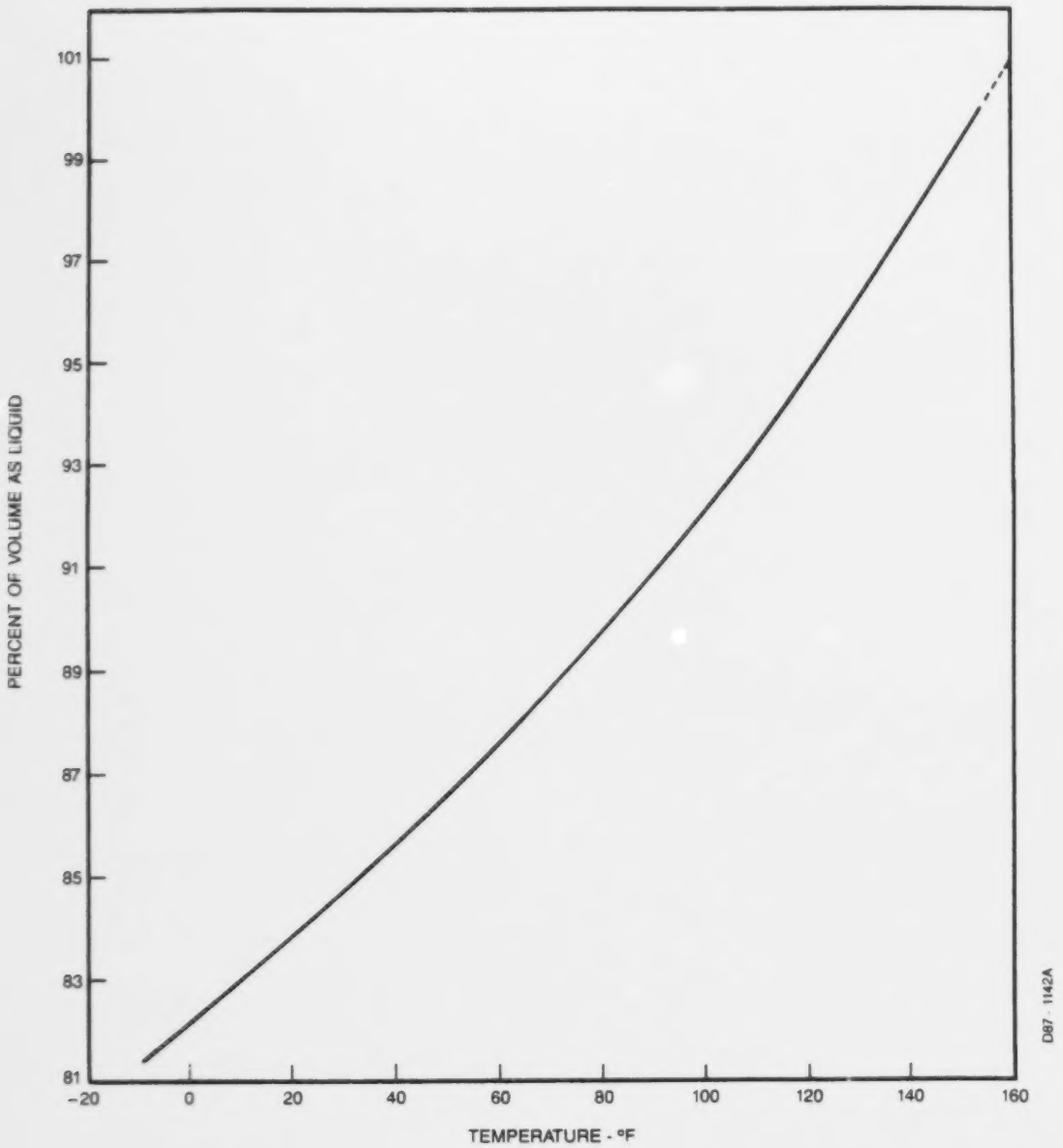

Figure 2-1. Volume - temperature relation of liquid chlorine in a container loaded to its authorized limit.

Source: Adapted from Reference 5.

support the burning of most combustible materials. Because chlorine is a strong oxidizer, it reacts readily with reducing agents. Chlorine reacts with metals and other elements, as well as with inorganic and organic compounds. The most significant chemical properties contributing to the potential for accidental releases are as follows:

- As a result of hydrolysis, moist chlorine contains hydrochloric and hypochlorus acids that are very corrosive to most common metals. Dry chlorine, however, tends not to react with metals until an activation temperature specific to the metal has been reached. Above this temperature, the reaction proceeds rapidly; carbon steel, for example, ignites in chlorine at 483°F (9). Titanium ignites upon contact with dry chlorine at ambient temperatures. Chlorine also can react explosively with powdered metals.

- Under certain conditions, chlorine will react rapidly with most of the elements. It will, for example, react violently with hydrogen to form hydrogen chloride. This explosive reaction can take place if either component is present at concentrations greater than approximately 15 percent in a mixture (10).

- Because of its great affinity for hydrogen, chlorine tends to remove hydrogen atoms from other compounds. For example, chlorine reacts with hydrogen sulfide to form hydrogen chloride and sulfur. Chlorine combines with carbon monoxide to form phosgene and with sulfur dioxide to form sulfuryl chloride. Both of these reaction products are toxic and corrosive. Chlorine reacts with ammonia or ammonium compounds to form various mixtures of chloramines, depending on the conditions. One of these chloramines is nitrogen trichloride, which becomes highly

explosive, even at relatively low concentrations in the range of a few percent.

- Chlorine dissolves rapidly in strong alkali solutions to produce hypochlorite solution. When chlorine is absorbed in alkali solutions, excess chlorine causes an acid condition that promotes the release of large quantities of chlorine and oxygen. This decomposition can occur with explosive force (10).

- Chlorine's strong oxidizing ability allows it to react vigorously with organics to form chlorinated derivatives and hydrogen chloride. Flammable gases and vapors can form explosive mixtures with chlorine. Some of these compounds include gasoline, alcohols, ethers, acetylene, oils, greases, organic solvents, and other hydrocarbons.

2.3 TOXICOLOGICAL AND HEALTH EFFECTS

Chlorine is a highly toxic, severe skin and lung irritant. The toxicological effects of chlorine have been well-documented, both from animal studies and from accidental human exposure (11,12).

Exposure to low concentration of chlorine causes a stinging or burning sensation in the eyes, nose, and throat; choking; and sometimes headache caused by irritation of the accessory nasal sinuses. There may be redness of the face, tearing, sneezing, coughing, and huskiness or loss of voice. Bleeding of the nose may occur and sputum from the larynx and trachea may be blood- tinged. Inhalation of chlorine in higher concentrations affects both the upper and lower respiratory tract and also produces pulmonary edema. The most pronounced symptoms are suffocation, constriction in the chest, and tightness in the throat. A concentration of 833 parts per million (ppm) breathed for 30 to 60 minutes has caused death (11). Skin contact with the

liquid or vapor may result in ulceration and necrosis. Table 2-2 presents a summary of some of the relevant exposure limits for chlorine. Table 2-3 presents a summary of predicted human health effects of exposure to various concentrations of chlorine.

TABLE 2-2. EXPOSURE LIMITS FOR CHLORINE

Limit	Concentration (ppm)	Description	Reference
IDLH	25	The concentration defined as posing an immediate danger to life and health (i.e. causes toxic effects for a 30-minute exposure).	13
PEL	1	A time-weighted 8-hour exposure to this concentration, as set by the Occupational Safety and Health Administration (OSHA), should result in no adverse effects for the average worker.	12
LC_{LO}	15	This concentration is the lowest published concentration causing toxic effects (irritation) for a 1-minute exposure.	12
TC_{LO}	430	This concentration is the lowest published lethal concentration for a human over a 30-minute exposure.	12

TABLE 2-3. PREDICTED HUMAN HEALTH EFFECTS OF EXPOSURE TO VARIOUS CONCENTRATIONS OF CHLORINE

ppm	Predicted Effect
3.5	Odor threshold
4	Maximum concentration tolerated without serious effects for a 1-hour exposure
30	Minimum concentration known to cause coughing.
40-60	May be dangerous in 30 minutes.
1,000	Likely to be fatal after only a few deep breaths.

Source: Adapted from Reference (4).

SECTION 3
FACILITY DESCRIPTIONS AND PROCESS HAZARDS

This section briefly describes the uses of chlorine in the SCAQMD and highlights major hazards related to accidental releases. Preventive measures associated with these hazards are discussed in Section 4.

3.1 PROCESSING

Chlorine's most important industrial uses are based on its properties as an oxidizer and on its general reactivity. Aliphatic compounds are chlorinated through addition and substitution reactions; aromatic compounds are chlorinated in a substitution process. Oxyhydrochlorination is the term used for the reactions that produce chlorinated organics. Chlorine is also used to produce a wide variety of inorganic chemicals; bleach production is a major use of chlorine. Another application for chlorine is water treatment, including purification of drinking water, treatment of wastewater and sewage, and treatment of cooling tower water.

Survey data indicate that the primary uses for chlorine in the SCAQMD are for water chlorination, bleach manufacture, chemical synthesis, and repackaging. This subsection summarizes the major technical features of typical processing and storage facilities that might be found in the SCAQMD, and discusses accidental release hazards associated with these facilities.

3.1.1 Drinking Water, Wastewater, and Cooling Tower Chlorination

Conventional chlorination facilities are composed of three parts: chlorine supply, metering system, and injector system. A typical liquid chlorine feed water chlorination system is shown in Figure 3-1. In some

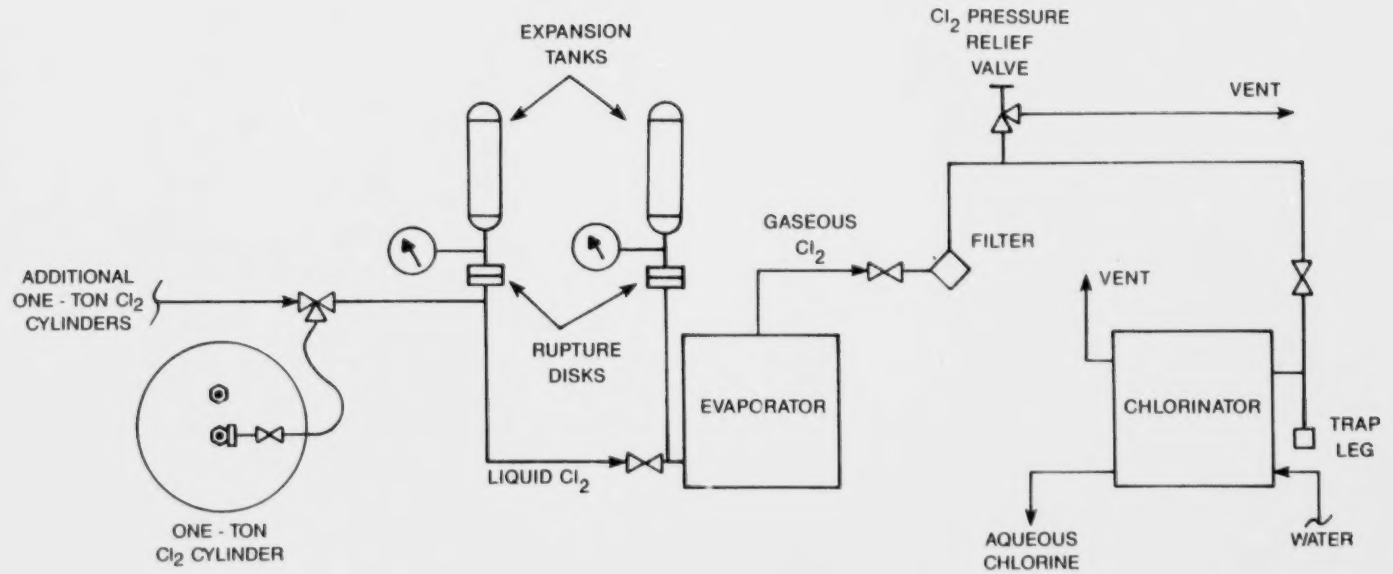

Figure 3-1. Conceptual process diagram of typical liquid chlorine feed chlorination system.

systems, instead of the liquid feed-evaporator system shown, chlorine gas is used directly as feed to the chlorinator. For chlorine supply, most facilities use chlorine packaged in containers ranging from 150-pound cylinders to single unit tank cars.

The chlorine gas metering system in a chlorination facility is known as the chlorinator. As shown in Figure 3-2, it consists of an inlet chlorine pressure regulating valve, a rotameter, a chlorine orifice, a manual feed rate adjuster, a vacuum differential regulating valve, a pressure-vacuum relief valve, and an injector. The vacuum created as water flows through the injector first opens the differential regulating valve, then the vacuum relief valve. This allows air to enter the system. This vacuum is also exerted on the inlet chlorine pressure regulating valve, allowing it to open, so that when the chlorine supply is open, the gas will flow through to the injector. As soon as the gas satisfies the vacuum created by the injector, the vacuum relief valve automatically closes, stopping the flow of air into the chlorinator. The following items are required for the safe control and operation of a chlorinator:

- Inlet chlorine pressure-reducing valve to reduce the cylinder pressure to a constant downstream pressure less than atmospheric;
- Manually and automatically adjustable chlorine metering orifice;
- Automatic pressure vacuum relief device;
- Rotameter for indicating chlorine feed rate;
- Differential vacuum regulating valve; and
- Chlorine pressure and injector vacuum gauges.

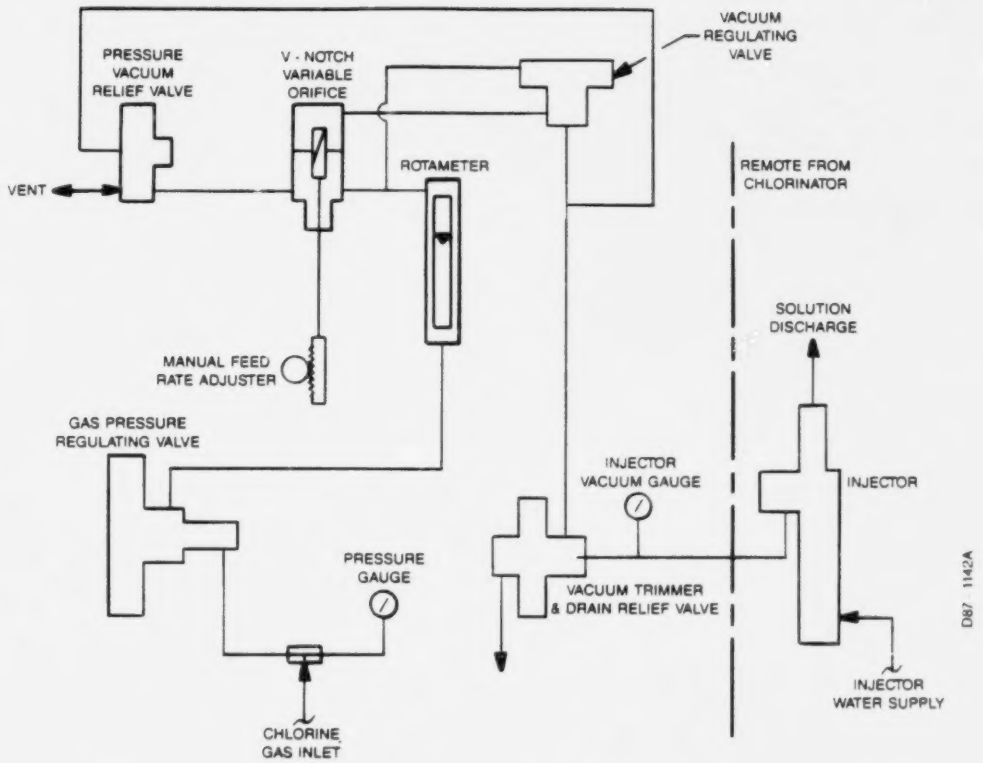

Figure 3-2. Conceptual diagram of typical chlorinator.

The injector is the primary functional component of the chlorinator. It develops the vacuum that causes the chlorine to flow from the storage supply through the chlorinator and then into itself. At the injector, the chlorine dissolves in water to form hypochlorous acid. This solution flows in the lines to the point of application. The injector system is usually composed of the following items:

- Water pressure gauge;
- Back pressure gauge located immediately downstream from the injector;
- Water pressure switch for the low water pressure alarm; and
- Water flow meters.

Remotely located injectors usually have a vacuum gauge and a vacuum line shutoff valve.

Additional information concerning the various types of chlorination facilities, equipment used, and specific design considerations is available from White (4).

The primary hazards associated with chlorination systems arise from the large inventory of stored chlorine and the chlorine evaporator. Excess feed to the evaporator or overheating could lead to overpressure and a possible release. The possibility of liquid chlorine feed lines being blocked while full of liquid also could lead to chlorine release.

Hazards associated with the handling and hookup of chlorine cylinders or containers include human errors that could cause damage, or faulty connections that could lead to a release. A chlorine container improperly connected to

the feed system could result in backflow of water into the cylinder, and internal corrosion that might go undetected until a failure occurs. Nitrogen is sometimes used for padding a chlorine feed tank or cylinder. Chlorine could enter a nitrogen line if the system were not designed correctly.

3.1.2 Bleach Production

Bleach is a hypochlorite solution prepared by the chlorination of sodium hydroxide or calcium hydroxide. The respective reactions are as follows.

$$2\ NaOH + Cl_2 \longrightarrow NaOCl + NaCl + H_2O$$

$$2\ Ca(OH)_2 + 2\ Cl_2 \longrightarrow Ca(OCl)_2 + CaCl_2 + 2H_2O$$

In both processes, chlorine is injected through sparge tubes into the caustic or lime solution. Sodium hypochlorite is referred to as liquid bleach; calcium hypochlorite is commonly called bleach liquor.

Liquid bleach is produced in stirred tank reactors, both batch and continuous, as well as in continuous packed-tube reactors. Typical stirred tank reactor systems are shown in Figures 3-3 and 3-4. Bleach liquor is also produced by both methods, but continuous production is preferred because of lower maintenance requirements.

Bleach production processes may include the following areas where problems could lead to highly hazardous conditions:

- Reaction stability (a function of solution pH);
- Chlorine feed rate control system;
- Reactor cooling system; and

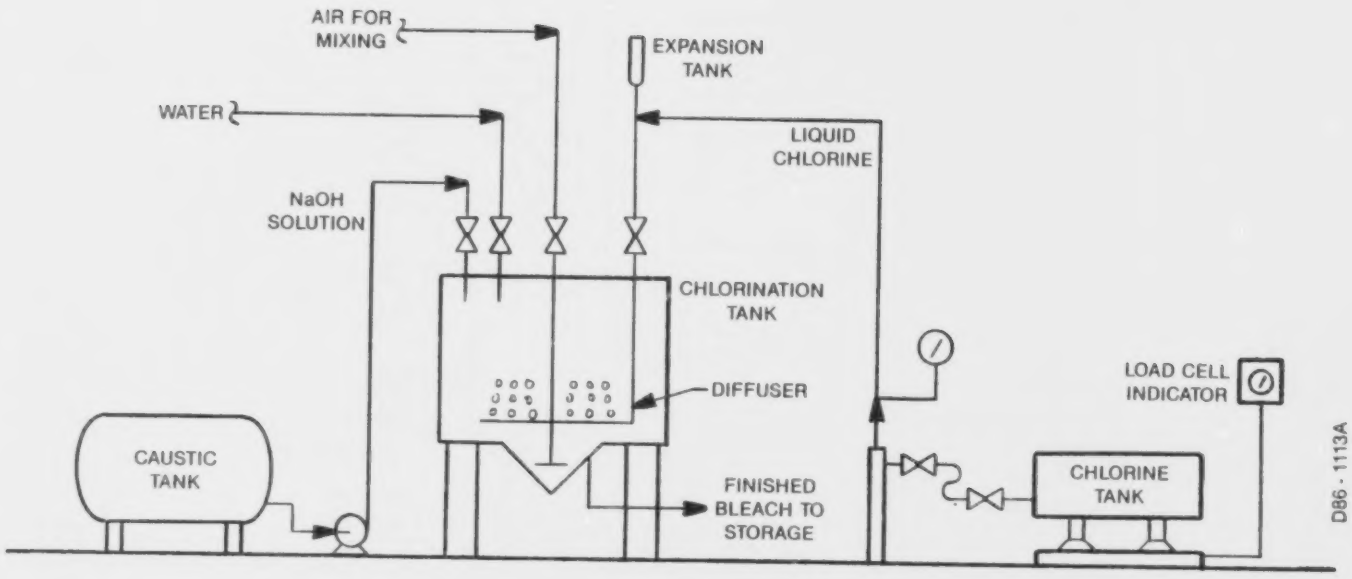

Figure 3-3. Conceptual process diagram of typical batch sodium hypochlorite manufacturing process.

Source: Adapted from Reference 14.

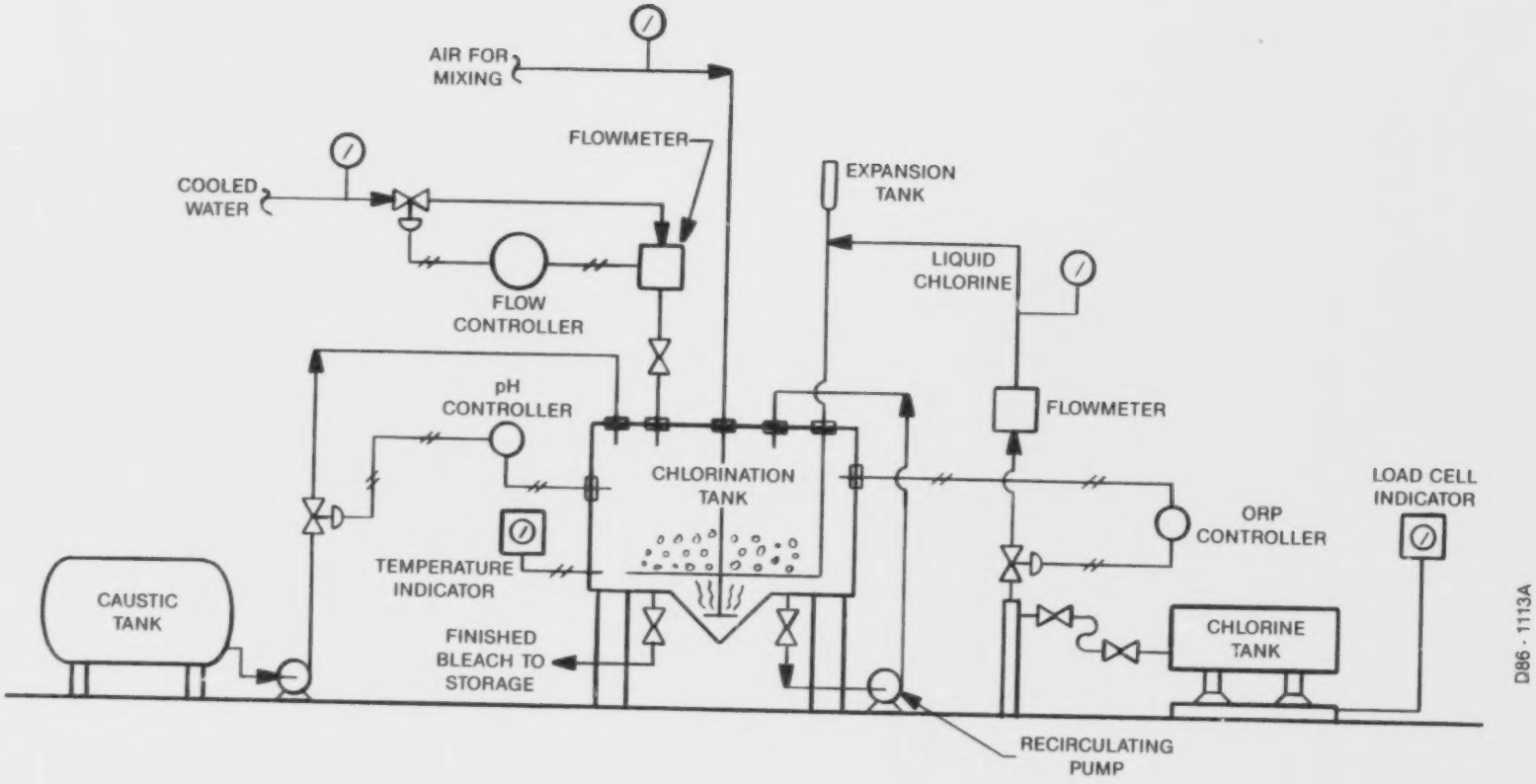

Figure 3-4. Conceptual process diagram of typical continuous sodium hypochlorite manufacturing process.

Source: Adapted from Reference 14.

- Batch reactor agitation.

When chlorine is absorbed in alkali solutions, the stability of the process is pH dependent. The pH of the solution should be monitored to ensure that free alkali is present, since excess chlorine can promote an acid condition causing the release of chlorine and oxygen. This decomposition can occur explosively (10). Poor control of the chlorine feed rate could cause such a process failure.

Chlorination of caustics is exothermic and liberates 44.34 Btu/lbmol when chlorine gas is used. Reactor cooling is required, which is partially achieved using liquid chlorine feed. Thorough agitation is necessary to prevent local overchlorination as well as to improve the effectiveness of both the cooling system and the oxidation potentiometer used to monitor the reaction (10). The primary hazard is a runaway reaction from an excess chlorine feed rate, cooling system failure, or loss of agitation.

3.1.3 Photochemical Chlorination

Photochemical chlorination is a process in which chlorine reacts with a hydrocarbon feedstock using ultraviolet light as the energy source for carrying out the reaction. Photochemical reactors can be batch or continuously operated. Figure 3-5 shows examples of both batch and continuous reactors. A batch reactor consists of a large, stirred, jacketed vessel with lamps inserted through the top. The lamps are usually nitrogen blanketed and water cooled. A continuous reactor is typically tubular, with individual lamps positioned along its longitudinal axis.

High hazard areas in this process include:

- Chlorine feed rate control;
- Cooling of reactor or lamps;

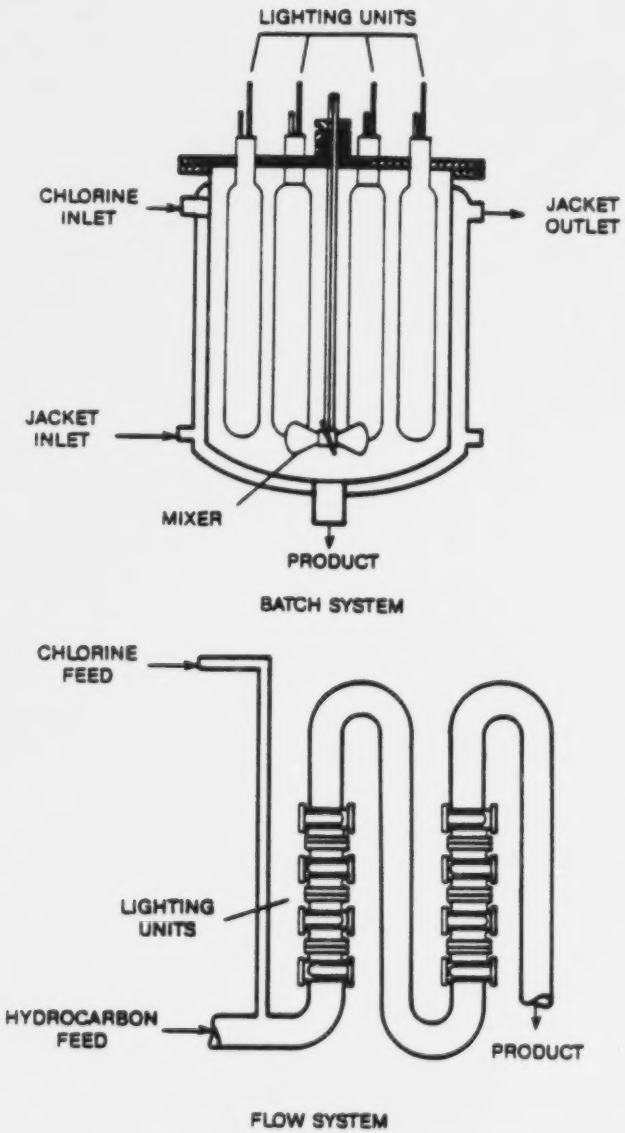

Figure 3-5. Photochlorination reactors.

- Agitation of reactants (in the batch process); and
- Seals on the reactor head or stirrer shaft.

An excessively high chlorine feed rate could overpressure the reactor or cause unreacted chlorine to pass through the reactors to downstream processing where it might cause a process upset leading to overpressure or emergency venting. Failure to cool the reactor lamps could cause the reaction rate to diminish, again resulting in a buildup of excess chlorine. A failure of agitation in the batch reactor could have a similar result, or could result in local overheating leading to equipment failure. For example, a physical lamp failure might result in a pressurized reaction mixture blowing out through the failed lamp assembly. Finally, a failure in reactor head or agitator seals could release chlorine.

3.2 REPACKAGING

In the SCAQMD chlorine is repackaged for resale and further use. Chlorine is commonly repackaged into cylinders. Hazards associated with this operation include overpressure, overfilling, mechanical damage, fire exposure, and chemical contamination.

The Chlorine Institute Pamphlet 8 (15) gives a detailed description of chlorine packaging plant operations. Equipment used in repackaging operations should be constructed of materials compatible with chlorine. Pressure relief systems are used to prevent possible equipment overpressure. Care is taken to prevent overfilling of cylinders.

3.3 STORAGE AND TRANSFER

When a facility uses large quantities of chlorine, it is unloaded directly from a rail car or from a rail car to stationary storage. The essential

components of a typical storage tank and tank car unloading system include a storage tank with a weighing device and sun shield, air padding system, eductor, chlorine gas and liquid headers, unloading platform, gages, pressure switches and alarms, flexible connections, and expansion tanks. The Chlorine Institute Pamphlet 66 (16) provides detailed information on chlorine tank car unloading. Figure 3-6 shows a typical tank car unloading facility (5,17).

Hazards associated with chlorine storage facilities include overpressure, overfilling, and corrosion. An additional hazard is associated with contamination caused by backflow of process materials into the storage tank. Backflow not only jeopardizes raw material quality, it also poses an accidental release hazard. For example, if backflow were to occur in a bleach manufacturing operation, caustic solution might be introduced to the chlorine storage tank where it could react exothermically, causing overpressure and discharge through a relief valve. If the overpressure relief system failed to function, the storage tank could be ruptured by the pressure, resulting in a catastrophic release.

While the above concerns also apply to refrigerated liquid chlorine storage facilities, the refrigeration system poses an additional concern. Loss of refrigeration could result in overpressure and a release through pressure relief devices due to thermal expansion of both the liquid and gaseous chlorine. Failure of such relief devices would result in equipment failure and a direct release.

3.4 POTENTIAL CAUSES OF RELEASES

Chlorine releases can originate from many sources, including ruptures in process equipment, separated flanges, actuated relief valves or rupture discs, and failed pumps or compressors. In addition, losses may occur through leaks at joints and connections such as flanges, valves, and fittings where failure of gaskets or packing might occur. Specific potential release sources within

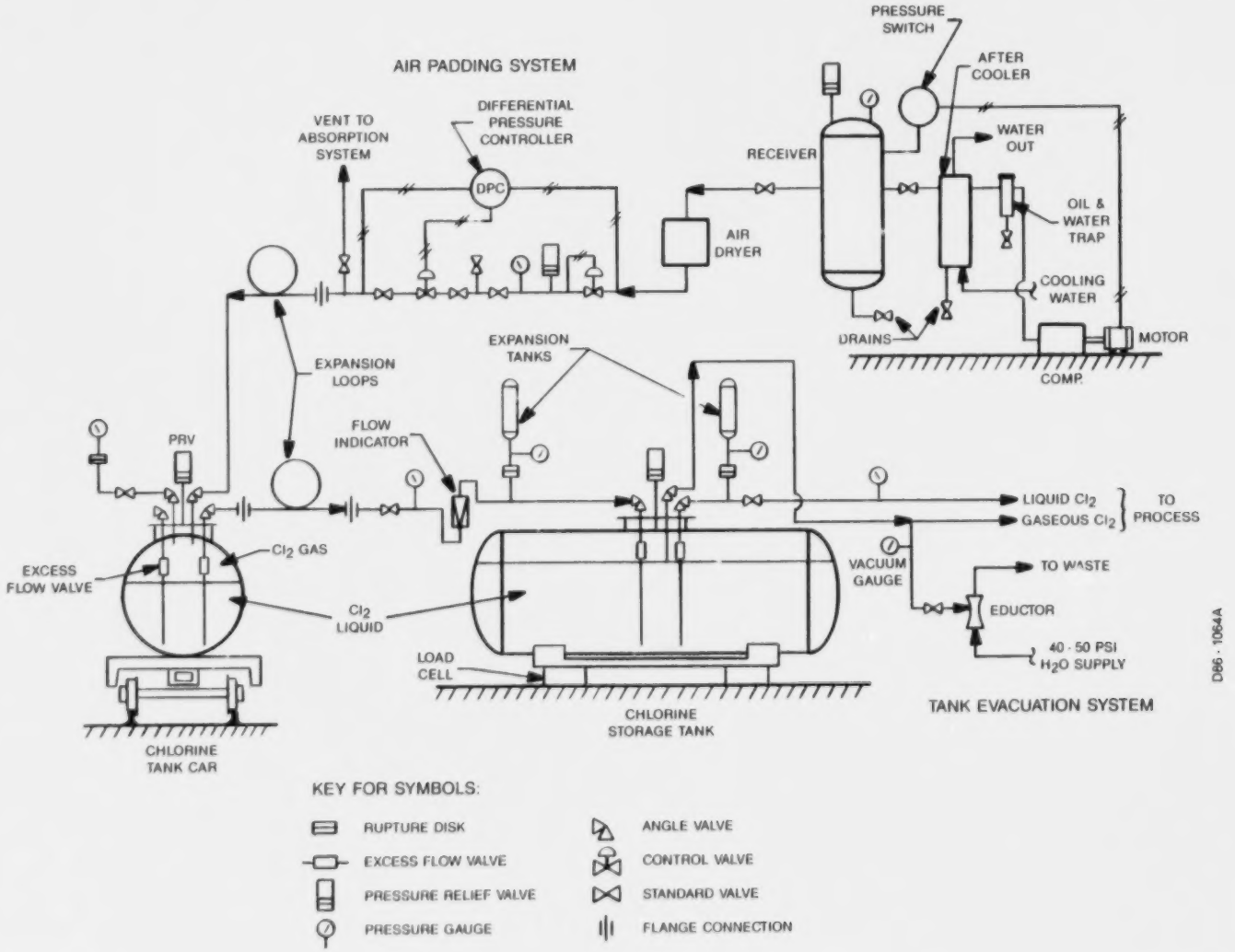

Figure 3-6. Typical bulk chlorine storage and tank car unloading system.

processes dominant in the SCAQMD were identified in preceding subsections of this manual.

Properties of chlorine that can promote equipment failure are its reactivity and its high liquid coefficient of thermal expansion. Reactivity manifested in corrosion is a likely general cause of equipment failure. Evaporators and metering and control equipment are especially sensitive if they are in intermittent use where moisture might enter the system.

Potential chlorine releases may be in the form of either liquid or vapor. Liquid spills can occur when chlorine is released at or below its boiling point of -29.3°F, or when a sudden release of chlorine at temperatures above -29.3°F results in vapor flashing, thus cooling at least part of the remaining material to -29.3°F. Direct releases of vapor or gas can also occur.

The extensive use of 150-pound cylinders and one-ton containers to store chlorine makes them a particular concern in the SCAQMD. A list compiled by the Chlorine Institute shows historical causes of chlorine container emissions in order of a combined ranking of frequency and size (4):

1. Fire;
2. Flexible connection failure;
3. Fusible plug failure;
4. Human error;
5. Valve packing failure;
6. Gasket failure;
7. Piping failure;
8. Equipment failure;
9. Collision; and
10. Container failure.

Although fire is not the most frequent hazard, it may be the most serious. Fire can melt the fusible plug of a container at 158°F, causing the

discharge of most of the chlorine in the container. Defective fusible plugs have also failed to melt, allowing a fire to rupture the container. A number of leaks have been caused by defective fusible plugs without a fire. Corrosion or poor bonding between the lead alloy plug and the plug retainer allows moisture accumulation and corrosion at the connection, leading to leakage of chlorine.

Probably the most frequent cause of chlorine emissions is failure of the copper tubes commonly used to connect cylinders and ton containers to process equipment. A corrosion cycle begins when the tube is disconnected for a container change. Moisture in the air enters the tube, promoting corrosion; repeated removal and reconnection of tubing will induce failure. Historically, other piping failures have been rare, but may have been caused by corrosion, thermal expansion of chlorine, or by impact damage.

Valve packing failure on the cylinders is usually a minor problem that can be corrected by tightening the packing nut. A potential hazard exists from overtightening if too large a wrench is used; a brass valve is easily damaged or broken. For serious leaks, the Chlorine Institute provides safety kits for each type of container (5).

Because of the strict standards and monitoring programs followed by chlorine packagers, container failures are very rare. In a period of 15 years, the Chlorine Institute accident reports indicate that of approximately 15 million 150-pound and ton containers shipped, only two had failures (4). Collisions with containers are rare, but are a possible cause of a release (4).

Causes leading to accidental chlorine releases may be due to process, equipment, or operational failures. The causes discussed below are intended to be illustrative, not exhaustive. A more detailed discussion of the possible causes of accidental releases will appear in other portions of the prevention reference manual series.

3.4.1 Process Causes

Process causes are related to the fundamentals of process chemistry, control, and general operation. Possible process causes of a chlorine release include:

- Excessively high chlorine feed rate to a bleach reactor leading to excessive exothermic reaction, combined with failure of the cooling system;
- Backflow of chlorination water to a chlorine cylinder;
- Loss of agitation in batch reactor systems;
- Excess chlorine feed leading to overfilling or overpressuring equipment;
- Photo-lamp failure in photochemical reactor; and
- Overpressure of chlorine storage vessel due to overheating from reactions. This situation may be caused by contamination, fire exposure, or unrelieved overfilling.

3.4.2 Equipment Causes

Equipment causes of accidental releases result from hardware failure, including:

- Excessive stress due to improper fabrication, construction, or installation;
- Failure of vessels at normal operating conditions due to weakening of equipment from excessive stress, external

loadings, or corrosion. Overheating is also a possibility, especially for chlorine evaporators and bleach reactors;

- Mechanical fatigue and shock in any equipment. Mechanical fatigue could result from age, vibration, or stress cycling, caused by pressure cycling, for example. Shock could occur from collisions with moving equipment such as cranes or other equipment in process or storage areas;

- Thermal fatigue and shock in bleach reactors and chlorine evaporation;

- Brittle fracture in any equipment, but especially in carbon steel equipment subjected to extensive corrosion. Equipment constructed of high alloys, especially high strength alloys selected to reduce the weight of major process equipment, might be especially sensitive where some corrosion has occurred, or severe operating conditions are encountered;

- Creep failure in equipment subjected to extreme operational upsets, especially excess temperature. This can occur in equipment subjected to a fire; and

- All forms of corrosion, including external corrosion from fugitive emissions of chlorine, could lead to equipment weakening. Stress corrosion cracking is also a possibility since this is characteristic of certain metals exposed to halogens.

3.4.3 Operational Causes

Operational causes of accidental releases result from incorrect operating and maintenance procedures or from human errors (i.e., not following correct procedures). These causes include:

- Overfilled storage vessels;
- Errors in loading and unloading procedures;
- Inadequate maintenance in general, but especially on pressure relief systems and other preventive and protective systems; and
- Lack of inspection and non-destructive testing of vessels and piping to detect corrosion weakening.

SECTION 4
HAZARD PREVENTION AND CONTROL

4.1 BACKGROUND

The prevention of accidental releases relies on a combination of technological, administrative, and operational practices that apply to the design, construction, and operation of facilities where chlorine is stored and used. Considerations in these areas can be grouped as follows:

- Process design;
- Physical plant design;
- Operating and maintenance practices; and
- Protective systems.

In each of these areas, consideration must be given to specific factors that could lead to a process upset or failure that could directly cause a release of chlorine to the environment, or result in an equipment failure that would cause the release. At a minimum, equipment and procedures should be examined to ensure they are in accordance with applicable codes, standards, and regulations. In addition, stricter equipment and procedural specifications should be followed if extra protection against a release is considered appropriate.

The following subsections discuss some specific considerations regarding release prevention. In addition, illustrative cost estimates for different levels of control as applied to storage and process facilities are also

included. More detailed discussion of each of these areas will be found in the manual on control technologies.

4.2 PROCESS DESIGN

Process design involves the fundamental characteristics of processes that use chlorine. An evaluation of process design includes considering how deviations from the design might initiate a series of events that could result in an accidental release. The primary focus is on how the process is controlled in terms of the basic process chemistry involved, and on the variables of flow, pressure, temperature, composition, and level. Additional considerations may include quantity measuring systems, mixing systems, fire protection, and process control instrumentation. Modifications that enhance process integrity would involve changes in quantities of materials used, process pressure and temperature conditions, the unit operations used, sequence of operations, the process control strategies, and the instrumentation used.

Table 4-1 shows the relationship between some specific key process design considerations and the individual processes described in Section 3 of this manual. This does not mean that other factors should be ignored, nor does it mean that proper attention to the key considerations ensures a safe system. It does mean that the designated key considerations must be properly addressed if a system is to be safe.

The most significant process design considerations are aimed at preventing overheating and overpressuring systems containing chlorine. If chlorine is fed under its own vapor pressure, the primary cause of overpressure would be overheating. Where chlorine is fed by nitrogen padding of a storage vessel or through pumps or compressors, overpressuring could occur without overheating. Equipment failure without overpressure is possible if corrosion has weakened process equipment. Temperature monitoring is important, not only because of potential overpressure or of equipment weakening due to overheating, but also because chlorine can react with many metals above a certain

TABLE 4-1. KEY PROCESS DESIGN CONSIDERATIONS FOR CHLORINE PROCESSES

Process Design Consideration	Process or Unit Operation
Contamination (with water and organics especially)	All
Flow control of chlorine feeds	All
Temperature monitoring; heating media flow control	Chlorination reactors in bleach processes and chlorine vaporizer in any feed system
Adequate pressure relief	All
pH monitoring	Bleach process
Mixing	Bleach process, batch photochlorination
Temperature monitoring; cooling media flow control	Bleach process, refrigerated storage
Corrosion monitoring	All
Temperature monitoring	All

activation temperature. Conversely, chlorine can cool itself while off-gasing and potentially reach temperatures below the safe operating range for some metals. In addition, vessels containing liquid chlorine at room temperature or above should be designed to be in the leak-before-fracture-failure region over the entire range of temperatures from the boiling point to maximum temperature and pressure of the vessel.

4.3 PHYSICAL PLANT DESIGN

Physical plant design involves equipment, siting and layout, and transfer/transport facilities. Vessels, piping and valves, process machinery, instrumentation, and factors such as location of systems and equipment must all be considered. The following subsections cover various aspects of physical plant design, beginning with a discussion of materials of construction.

4.3.1 Equipment

Materials of Construction--

The two most important considerations in selecting materials for chlorine service are the temperature and moisture content of the chlorine. The temperature is important because the corrosiveness of chlorine increases with increasing temperature, and most metals will ignite at a given temperature in the presence of chlorine. The moisture content is also critical because, though dry chlorine is noncorrosive (at normal to moderate temperatures), moist or wet chlorine is very corrosive to most metals.

Equipment construction materials must be chosen to prevent deterioration or product contamination. Steel, cast iron, wrought iron, most copper alloys, most nickel alloys, certain stainless steel, and lead are common materials of construction for chlorine processes (1). Other materials resistant to the corrosiveness of wet chlorine are titanium, nickel-copper and nickel-chromium-molybdenum alloys, high silica iron, platinum, silver, tantalum, and zirconium. While titanium may be used with wet chlorine, it reacts rapidly, even

violently, with dry chlorine. Tantalum is inert with both wet and dry chlorine up to 300°F (5). For handling wet chlorine at low pressures, suitable materials include hard rubber, unplasticized polyvinyl chloride, polyvinylidine chloride, fully-halogenated fluorocarbon resins, reinforced polyester resin, or certain other non-metallics (5,10). Before one of these materials is chosen, the conditions and requirements of the chlorine system must be considered carefully. Many of the non-metals can be used as lining materials in higher pressure wet chlorine systems that require the strength of metals and the chemical resistance of polymers. Chlorination vessels and reactors are often constructed of fiberglass-reinforced plastic (FRP) or of carbon steel lined with a polymeric material.

Table 4-2 compares the corrosion resistance of a number of common metals and alloys in the presence of dry chlorine. (10). The usual material of construction for dry chlorine at moderate temperatures is mild steel. However, since wet chlorine severely attacks this metal, it is essential to exclude water from chlorine systems that use mild steel. The typical water content of commercial chlorine is 20-60 ppm; this is considered acceptable with the common materials of construction. The corrosiveness of chlorine on mild steel also is temperature dependent. Corrosion of mild steel is significant at 392°F and rapid at around 446 °F. It is typical to restrict the use of mild steel to applications where the chlorine temperature is below about 248°F (1). Below 248°F, iron, copper, lead, nickel, platinum, steel, silver, and tantalum are chemically resistant to dry chlorine gas or liquid (10).

Vessels--

The predominant vessels that appear to be involved in chlorine service in the SCAQMD include storage cylinders, fixed storage tanks, rail cars used for storage, evaporators, and chemical reactors. The role of these vessels in chlorine service was discussed in Section 3.

Chlorine storage vessels likely to be encountered in the SCAQMD range in size from 150-pound pressure cylinders to multi-thousand ton, spherical

TABLE 4-2. CORROSION OF METALS IN DRY CHLORINE

	Approximate temperature (°F) at which given corrosion rate is exceeded in short-time tests in dry Cl_2[a]				
	0.0025 in. per month	0.005 in. per month	0.05 in. per month	0.05 in. per month	0.1 in. per month
nickel	950	1,000	1,100	1,200	1,250
Inconel	950	1,000	1,050	1,200	1,250
Hastelloy B	950	1,000	1,100	1,200	
Hastelloy C	900	1,000	1,050	1,200	
Hastelloy A	900	1,000	1,100	1,200	
platinum	900	950	1,100	1,050	1,250
magnesium	850	900	950	1,000	1,050
Chromel A	850	900	1,000	1,150	1,050
Monel	750	850	900	1,000	
18-8-Mo stainless steel	600	650	750	850	1,000
18-8 stainless steel	550	600	650	750	900
Hastelloy D	400	450	550		850
deoxidized copper	350	450	500	500	550[b]
carbon steel	250	300	300	350	350[d]
aluminum 2S	250	300	300	350	350[d]
gold	250	300	350	400	400
cast iron	200	250	350	450	450[c]
silver	100	150	150	450	500

[a] These values are based on short-time laboratory tests under controlled conditions. They should be interpreted only as being indicative of the limitations of the materials, and should not be used for estimation of the service life of equipment.

[b] Ignites at about 601°F.

[c] Ignites at 450-500°F.

[d] Ignites at 400-450°F.

Source: Adapted from Reference 9.

refrigerated chlorine storage tanks. Because of the relatively large inventories contained in chlorine storage vessels, they represent one of the most hazardous areas within a chlorine system. The vessels most commonly used for transfer and storage of chlorine are well standardized and are described in detail in various Chlorine Institute literature (17,18,19). These containers include: cylinders up to 150-pound capacity, one-ton containers, 15-ton containers, single-unit tank cars (16, 30, 55, 85, and 90 tons capacity), 15- to 20-ton tank trucks, and 150- to 300-ton barge tanks. Up to about 450 tons of chlorine may be stored safely in high strength tanks as a liquid under pressure. Larger quantities are usually stored at atmospheric pressure as a refrigerated liquid in single and double-walled horizontal cylindrical or spherical vessels (5,10). Detailed design considerations are found in Chlorine Institute Pamphlet 78: "Refrigerated Liquid Chlorine Storage" (18).

Rail cars in chlorine service must meet Department of Transportation (DOT) Specifications (16).

Vaporizing equipment for chlorine is available in capacities ranging from 400 lb/day to 10,000 lb/day (19). Several types of vaporizers including electric heat, hot water, and steam types are used in chlorine service. Detailed design considerations are available in Chlorine Institute Pamphlet 9: "Chlorine Vaporizing Equipment" (19).

The Chlorine Institute specifies that chlorine vaporizing equipment must be protected by a pressure relief device (19). For most chlorine vessels, overpressure protection is provided by an adequate overpressure relief venting system that cannot be isolated from service. The relief system should be sized for flashing liquid caused by:

- Fire exposure;
- Thermal expansion;

- Internal reaction/decomposition; and

- Excess supply rates.

Release prevention considerations for all vessels include prevention of: overpressure, overfilling, overheating, and corrosion. With liquid chlorine, overfilling and overheating are especially important because of the high coefficient of thermal expansion associated with liquid chlorine.

Overpressure protection of vessels is provided by relief devices. These devices protect against catastrophic rupture or explosion by allowing a controlled release of overpressured contents. The types of devices used depend on the vessel service and on the potential causes of overpressure. Relief devices for overpressure caused by fire or other overheating of 150-pound cylinders and ton containers are usually fusible metal plugs which melt between 158°F and 165°F. The normal service seen by cylinders or ton containers does not usually require other overpressure protection of the cylinders or ton containers themselves. When cylinders are padded with nitrogen to pressure-feed chlorine at pressures above its vapor pressure, overpressure protection should be provided in the nitrogen feed system. This ensures that the nitrogen cannot exceed the working pressure of the chlorine vessels or any parts of the downstream system connected to these vessels. Chlorine cylinders and ton containers themselves are rated for several hundred pounds per square inch (5). In addition, a check valve should be installed on the nitrogen feed line to insure that no chlorine enters the nitrogen supply system.

Larger vessels are usually equipped with pressure relief valves and rupture disks. A rupture disk upstream of a relief valve is a common configuration in chlorine service since chlorine tends to corrode pressure relief valves. In addition to general provisions of good practices for the design and sizing of relief devices (1), these devices should be sized according to guidelines given by the Chlorine Institute as a minimum standard (20). These

guidelines include materials of construction, flow capacity, connections, and relief system configuration.

Chlorine tank cars are equipped with spring-loaded safety relief devices that have a breaking pin assembly designed to function at a specified pressure. Tank trucks are similarly equipped.

It should be noted that while these devices are designed to prevent a catastrophic sudden release of vessel contents, a significant release of chlorine to the air could still occur. Protection from such an event might be achieved if the relief device discharge were routed to a caustic scrubber. Scrubber protection systems are discussed in Subsection 4.4 of this manual.

The pressure relief considerations discussed above also apply to chlorine evaporators and reactors except that there is a greater likelihood of two-phase flow in these cases. The effect of two-phase flow on relief device design should be taken into account since it could result in a design different from that specified by the Chlorine Institute for chlorine storage system relief devices.

Prevention of overfilling can be accomplished with level-sensing devices, pressure relief devices, and adequately trained personnel. Level-sensing devices for chlorine service must be selected while taking into account the corrosiveness of chlorine, especially when it's in contact with moisture. Relief devices for overfilling may be the same or similar to those used for gas pressure relief. The overfill relief would discharge to an overflow tank or other suitable receiver. Consideration should be given to two-phase flow in the design of such relief systems. A short vented dip pipe can protect against the overpressure of a tank with a domed or arched roof filled with liquid chlorine with little or no vapor space. Relief from overpressure by liquid thermal expansion can be achieved with a relief device.

Because of the high coefficient of thermal expansion, the weight of chlorine in a tank must not exceed the nominal chlorine capacity of the tank or exceed 125% filling density (125% of the weight of water at 60°F that the tank will hold). The Chlorine Institute recommends having two tanks, each 20 percent larger than the shipping tank. This allows continuous operation and complete unloading of tank cars.

The Chlorine Institute provides guidelines on the materials of construction for stationary storage tanks (17). Except where the Institute indicates otherwise, the tanks should be constructed according to parts UW and UCS of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1. Tanks usually are constructed of normalized carbon steel. To allow for corrosion, the wall thickness should be 1/8 inch greater than that required by the design formula in the Code. The tank should be designed so that it can accept a tank car dome assembly, which can be purchased from chlorine tank car manufacturers. In the event of leakage, these assemblies allow the use of Chlorine Institute Emergency Kit "C" (5).

In addition to venting provisions, the containers should have valve arrangements that allow the vessel to be isolated from the process to which the chlorine is being fed. In addition, concerns about corrosion dictate that moisture be excluded from the tanks. Tanks should not be situated in standing water and care should be taken to prevent exposure to moist air, for instance, by applying a moisture proof material to the outside of the vessel. External corrosion can be as important as internal corrosion since air always contains moisture and minor leaks could lead to equipment failure.

A further concern is backflow of material into the storage vessels. When chlorine is absorbed in a liquid, the potential exists for the liquid to be drawn back into the chlorine container. This has resulted in numerous accidents. Such backflow can be prevented by a vacuum-breaking device or a barometric leg, check valves, and positive displacement pumps, or combination of the above (5).

Careful attention should be given to vessel corrosion; vessels in chlorine service should be constructed of suitable materials with adequate corrosion allowances. Special attention should be given to welds and to external corrosion under insulation.

Piping--

As with chlorine vessels, chlorine pipework design must reflect the pressure, temperature, and corrosion concerns associated with the use of chlorine. The first general guideline is simplicity of design; the number of joints and connections should be minimized. In addition to being securely supported, pipes should be sloped, with drainage provided at the low points. Piping should be constructed to allow room for thermal expansion of the pipe and should be protected from exposure to fire and high temperatures. Valves should be placed so that leaking pipes and equipment may be isolated, but no section of piping should be isolable from some form of overpressure relief or expansion chamber.

Piping and associated equipment should also be dry and grease- and oil-free since chlorine can react vigorously with organic compounds. Valves and instrumentation should be supplied by the manufacturer as "degreased and dried for chlorine duty."

For dry chlorine systems, carbon steel pipe is commonly used. Carbon steel such as ASTM A106 or seamless ASTM A53 is suitable in many cases. Materials not recommended include aluminum, titanium, tin, ordinary grey iron, malleable iron fittings, general purpose valves, and porcelain valves.

Chlorine Institute Pamphlet 6, "Piping Systems for Dry Chlorine" (20) contains detailed information on materials of construction for pipes, fittings, flanges, valves, gaskets, nuts, bolts, unions, and other components of a dry chlorine system. Table 4-3 summarizes Chlorine Institute recommendations for piping materials for given operating temperature ranges.

TABLE 4-3. SUMMARY OF CHLORINE INSTITUTE PIPING MATEKIAL RECOMMENDATIONS

Phase	Temperature Range (°F)	Maximum Pressure (psia)	System	Pipe Specifications				
				Size	Schedule	ASTM	Grade	Type
Gas	-20 to 300	≤150	Class[a] 150, Carbon Steel	3/4 - 1-1	80	A53	A,B	S
				2 - 6	40	A106		
Gas, Liquid	-20 to 149	≤300	Class[a] 300, Carbon Steel	3/4 - 1-1/2	80	A106	A,B	S
				2 - 6	80	A53	A,B	S
Gas, Liquid	-50 to 300	≤300	Class 300, Alloy Steel	--	--	A333	1	
Gas, Liquid	-150 to 300	≤300	Class 300, Alloy Steel	--	--	A333	3	

Source: Adapted from Reference 20.

[a]ANSI class refers to pressure ratings at specified temperature asset by the American National Standards Institute (ANSI). For a carbon steel flange, Class 150 means a 150 psig pressure rating at 500°F, and Class 300 means a 300 psig pressure rating at 850°F.

A chief concern in liquid chlorine lines is overpressure due to thermal expansion of the chlorine, or pressure pulses caused by rapid valve closure. Such pressures can rupture the pipes. Where applicable, an expansion chamber, such as the one shown in Figure 4-1, may be installed to prevent a rupture caused by thermal expansion. An expansion chamber device typically consists of a rupture disc and a receiver chamber which can hold about 20-30% of the capacity of the protected line. The chamber is equipped with a pressure indicator or alarm switch set to function on rupture. The chamber should be constructed in accordance with Section VIII of the ASME Code for Unfired Pressure Vessels (17). Sudden pressure pulses can be avoided by selecting valves that do not close abruptly.

Another concern in liquid chlorine systems is low temperature. Materials must be carefully selected when temperatures are significantly below ambient. The materials chosen should be resistant to brittle fracture over the entire range of process conditions. The Chlorine Institute Pamphlet 6 (20) provides additional information on materials of construction for low temperature operation.

The extremely corrosive nature of wet chlorine requires special corrosion-resistant materials, depending on the requirements and operating conditions of the system. Wet chlorine corrodes all the common construction metals; however, nickel-copper and nickel-chromium-molybdenum alloys are widely used. Tantalum is inert to both wet and dry chlorine. Titanium can be used with wet chlorine, but reacts violently with dry chlorine. Lined pipes can be used if the lining materials are chosen according to the operating conditions. Some polymer lining materials that are inert to chlorine include: tetrafluoropolyethylene, polyvinylidine fluoride, and ethylene chloro-trifluoro-ethylene. Polymeric materials that may be used in chlorine service for limited purposes include polyvinylidine chloride, polyvinyl chloride, chlorinated polyvinyl chloride, acrylonitrile butadiene styrene, polyethylene, polypropylene fiberglass-reinforced polyester, and hard rubber (5,20). If lined pipes are used, it is important that the integrity of the lining be

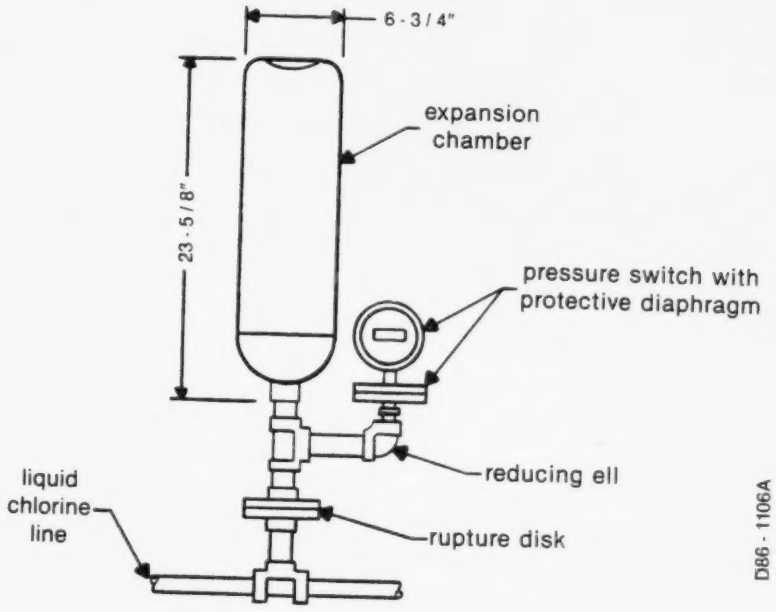

Figure 4-1. Liquid chlorine expansion chamber for liquid chlorine only. (Exact specifications for materials and fittings are provided in Reference 14. Substitutions should not be made without consultation with a recognized authority on chlorine system design and construction.)

maintained. Penetration of chlorine through the liner could lead to insidious, undetected pipe wall corrosion beneath the liner.

Many of the considerations for piping also apply to valves. Valves for chlorine service should be strong enough to withstand the expected pressure, resistant to corrosion, easy to remove and maintain, and should have a leak-tight gland or be leakproof, for example, diaphragm or bellow-sealed valves. Table 4-4 summarizes the guidelines for valve selection (20).

Ball and plug valves must be designed so that excess pressure in the body cavity (as well as in the ball or plug) will relieve spontaneously toward the high pressure side. This is accomplished by providing a relief hole in the valve body (or the ball or plug) which bypasses the upstream seat. Modified valves such as these must indicate the flow direction on the valve body. The valve stem seals should be externally adjustable to stop stem leakage, and the stem should not be removable while the valve is in service (20). All valves must be supplied and maintained dry as well as grease- and oil-free.

Because of the corrosiveness of chlorine, spring-loaded or gravity-operated check valves may not be suitable to prevent backflow. Instead, power-operated control valves with suitable instrumentation may be preferable for primary service with a check valve backup (20).

Excess flow valves are used in chlorine vessels, tank cars, and areas where unintentional high liquid discharge rates need to be prevented. In the event that a liquid discharge line is broken, the resulting high flow rate would cause the valve to close off, restricting the escape of chlorine. The Chlorine Institute has detailed information on valve materials, designs, and size for excess flow valves (16).

For maintenance and emergencies, it is often useful to be able to isolate vessels and other chlorine process equipment. In some cases, however, a single valve is insufficient to ensure complete isolation, and the use of slip

TABLE 4-4. SUMMARY OF CHLORINE INSTITUTE GUIDELINES FOR VALVES

Chlorine Phase	Temperature Range (°F)	Maximum Pressure (psia)	Valve Type	Rating (lb)	Class	Connection	Material
Gas	-20 to 300	≤150	Globe	800	-	Screwed	Forged Steel
			Ball	300	-	Screwed	Cast Steel
			Plug	300	-	Screwed	Ductile Iron
			Globe	-	150	Flanged	Cast Steel
			Ball	-	150	Flanged	Ductile Iron
			Plug	-	150	Flanged	Ductile Iron
Gas, Liquid	-20 to 300	≤300	Globe	800	-	Screwed	Forged Steel
			Ball	800	-	Screwed	Cast Steel
			Plug	300	-	Screwed	Ductile Iron
			Globe	-	300	Flanged	Cast Steel
			Ball	-	300	Flanged	Cast Steel
			Plug	-	300	Flanged	Cast Steel

Source: Adapted from Reference 20.

plates or a double block and bleed arrangement may be necessary. Because of the potential for releasing trapped chlorine, proper training is essential to ensure safe operation of these isolation techniques.

Process Machinery--

Process machinery refers to rotating or reciprocating equipment that may be used in the transfer or processing of chlorine. This includes pumps and compressors that may be used to move liquid or gaseous chlorine where gas pressure padding is insufficient or inappropriate.

Pumps--Many of the concerns and considerations for chlorine piping and valves also apply to pumps. To assure that a given pump is suitable for chlorine service, the system designer should obtain information from the pump manufacturer certifying that the pump will perform properly in this application.

Pumps should be constructed of materials resistant to chlorine at operating temperatures and pressures. They should be installed dry and oil-free. It is especially important that their design not allow chlorine or lubricating oil to enter seal chambers where they may contact one another. Net positive suction head (NPSH) considerations are especially important for chlorine since pumping the liquid near its boiling point may be common (chlorine is a gas at typical ambient conditions). The pump supply tank should have high and low level alarms; the pump should be interlocked to shut off at low supply level or low discharge pressure. External pumps should be situated inside a diked area and should be accessible in the event of a tank leak.

In many cases, the potential for seal leakage rules out the use of rotating shaft seals. One solution is to use pump types that isolate the seals from the process streams. The seals are typically cartridge canister double type (21). The buffer fluid between the mechanical seal is commonly light oil. Another solution is to use pump types that eliminate shaft seals

altogether, such as canned-motor, vertical extended-spindle submersible, magnetically-coupled, and diaphragm (21).

Canned motor pumps are centrifugal units in which the motor housing is interconnected with the pump casing. Here, the process liquid actually serves as the bearing lubricant. An alternative concept is the vertical pump often used on storage tanks. Vertical pumps consist of a submerged impeller housing connected by an extended drive shaft to the motor. The advantages of this arrangement are that the shaft seal is above the maximum liquid level (and is therefore not made wet by the pumped liquid) and the pump is self priming because the liquid level is above the impeller.

The Chlorine Institute suggests that vertical pumps be provided with double-packed seal chambers designed to prevent contact of chlorine and any reactive material. Seal gas should be dry, oil-free, and inert to chlorine. They recommend that the seal gas pressure be at least 10 psi over tank pressure, and that a seal gas back-up system be considered (20).

Magnetically-coupled pumps replace the drive shaft with a rotating magnetic field as the pump-motor coupling device. Diaphragm pumps are positive displacement units in which a reciprocating flexible diaphragm drives the fluid. This arrangement eliminates exposure of packing and seals to the pumped liquid.

Centrifugal pumps often have a recycle loop back to the feed container which prevents overheating in the event that the pump is deadheaded (i.e., the discharge valves close). This is an important consideration in chlorine systems since the corrosiveness of chlorine increases rapidly with increasing temperature. Deadheading also is a concern with positive displacement pumps. To prevent rupture, positive displacement pumps commonly have a pressure relief valve that bypasses to the pump suction. Because of the probability of eventual diaphragm failure, the hazard potential of diaphragm pumps should be carefully considered.

Pumps are not always necessary; in many circumstances, liquid chlorine is moved by pressure padding. With chlorine cylinders and ton containers, the liquid may be displaced from the vessel by the force of chlorine vapor pressure. As discussed earlier, this process is temperature dependent. With other types of vessels, an inert gas such as dry nitrogen may be used to force liquid from the tank. Padding system designs must reflect the operating conditions and limitations (e.g., required flow rate) and therefore must be custom designed for a process.

Compressors--Chlorine compressors include reciprocating, centrifugal, liquid-ring rotary, and non-lubricated screw compressors. Detailed descriptions of these compressors can be found in the technical literature (3).

Like pumps, compressors have the potential for heat buildup and shaft seal leakage. Heat sources in a compressor include the heat of compression as well as the heat generated through mechanical friction. Heat buildup in chlorine compressors is a particular concern because chlorine corrosion increases with increasing temperature. Most multistaged compressors can be equipped with intercoolers that limit heat buildup and increase compressor efficiency by reducing the volume of gas going to the next compression stage. Both air and water cooling are used, but water systems must be designed to prevent leakage and mixing of water and chlorine gas.

While it is often possible to avoid using rotary shaft seals with chlorine pumps, compressors in chlorine service usually require special seals such as double labyrinth seals. These seals have a series of interlocking touch points which, by creating many incremental pressure drops, reduce total leakage. To further reduce leakage, dry air is injected into the seal. In the event of deadheading, a compressor discharge can have a pressure relief mechanism that vents to the compressor inlet or to a scrubber system. The former appears to be satisfactory for a short term downstream flow interruption. Where a sustained interruption might occur, relief to a scrubber system would be safer.

Miscellaneous Equipment--

Pressure Relief Devices--For transportation equipment, the Chlorine Institute has drawings and specifications for chlorine relief valves. For vessels, an acceptable relief valve is of angle body construction with a closed bonnet and a screwed cap over the adjusting screw. These valves normally are used in combination with a rupture disc or a breaking pin assembly. Typical valve construction materials include a cast carbon steel body; a nickel-plated steel spring; and nickel-copper or nickel-chromium-molybdenum alloy nozzle, disc adjusting ring, nozzle ring, and spindle guide. The inlet flange should be Class 300 and the outlet flange should be Class 150 or 300. Valves of this construction that also have Viton® "O" ring seat seals need not have a rupture disc or breaking pin. Other types of pressure relief devices are acceptable as long as they are constructed of materials suitable for chlorine service and meet the general requirements of the ASME boiler and Pressure Vessel Code, Section VIII, Division 1 (20).

Rupture discs are constructed of chlorine-resistant materials such as silver, tantalum, or impervious graphite. Since impervious graphite rupture discs fragment on overpressure, they should not be used in conjunction with relief valves. Connections smaller than two inches can be screwed, flanged or socket-welded; connections two inches or larger should be flanged or butt-welded. The flanges should be constructed of forged carbon steel and be rated in accordance with their associated piping system. Because operating pressures exceeding 70% of disc burst pressure may induce premature failure, a considerable margin should be allowed when sizing rupture discs. When it is possible to draw a vacuum on the disc, supports should be provided (19).

Measures should be taken to ensure that process equipment is not isolated from its relief system. To provide continuous pressure relief protection, when a device is out of service for maintenance, equipment may be provided with dual relief systems, each sized to provide the total required flow capacity. Piping and valves should be arranged so that one of the systems

always provides protection. Stop valves installed between a vessel and its relief device should have a full port area at least equal to that of the pressure relief device inlet. These valves should be locked open or have handles removed when the protected vessel is in use. If the discharge is to be piped to a closed disposal system, such as a scrubber, the pressure drop caused by the additional piping must be considered and the relief device sized accordingly. Relief device sizing guidelines are given in Chlorine Institute Pamphlet 5 (17).

Instrumentation--A primary consideration for instrumentation in chlorine service is corrosion resistance. Diaphragm pressure switches usually have a diaphragm constructed of silver, tantalum, or nickel-copper alloy. The upper body seal is steel, and the lower body seal is steel or nickel-copper alloy. Direct reading pressure gauges often have a nickel-copper alloy bourdon tube. The pressure range for both types of pressure measurement devices should be twice the operating pressure (20). Other instrumentation, such as temperature and flow measurement devices, also should be constructed of chlorine resistant materials.

4.3.2 Plant Siting and Layout

The siting and layout of a particular chlorine facility is a complex issue that requires careful consideration of numerous factors, including: other processes in the area, the proximity of population centers, prevailing winds, local terrain, and potential natural external effects such as flooding. The rest of this subsection describes general considerations that might apply to the siting and layout of chlorine facilities.

Siting of facilities or individual equipment items should minimize personnel exposure, both plant and public, in the event of a release. Since other siting considerations are also important, there may be trade-offs between this requirement and others. The site should provide ready ingress or egress in the event of an emergency and yet also take advantage of barriers,

either man-made or natural, that could reduce the hazards of releases. Large distances between large inventories and sensitive receptors is desirable.

Layout refers to the placement and arrangement of equipment in the process facility. Some general layout considerations include the following:

- Large inventories of chlorine should be kept away from sources of fire or explosion hazard;
- Vehicular traffic should not go too near chlorine process or storage areas if this can be avoided;
- Where such traffic is necessary, precautions should be taken to reduce the chances for vehicular collisions with equipment, especially pipe racks carrying chlorine across or next to roadways;
- Chlorine piping preferably should not be located adjacent to other piping which is under high pressure or temperature, or which carries flammable materials;
- Storage facilities should be segregated from the main process unless the hazards of pipe transport are felt to outweigh the hazard of the storage tank for site-specific cases; and
- Storage should also be situated away from control rooms, offices, utilities, storage, and laboratory areas.

Various techniques are available for formally assessing a plant layout and should be considered when planning high hazard facilities handling chlorine (1). These techniques provide for a systematic evaluation of key siting and layout factors.

Because heat increases chlorine corrosiveness and causes thermal expansion of liquid chlorine, measures should be taken to situate piping, storage vessels, and other chlorine equipment to minimize heat exposure. Hot process piping, equipment, steam lines, and other sources of direct or radiant heat should be avoided. Storage should also be situated away from control rooms, offices, utilities, storage, and laboratory areas. Special precautions should be taken to keep chlorine storage vessels away from potential fire or explosion sources.

In the event of an emergency, there should be at least two means of access to the facility for emergency vehicles and crews. Storage vessel shut off valves should be readily accessible. Containment for liquid storage tanks can be provided by diking. Dikes reduce evaporation while containing the liquid. It is also possible to equip a diked area to allow drainage to an underground containment sump. This sump would be vented to a scrubber system for safe discharge. A full containment system using a specially constructed building vented to a scrubber is another possible option. This type of secondary containment could be considered for large volume, liquid chlorine storage tanks. However, secondary hazards abound with such a system and extreme care in layout and design are required to protect the operators.

4.3.3 Transfer and Transport Facilities

Transfer and transport facilities where both road and rail tankers are loaded or unloaded are likely accident areas because of vehicle movement and the intermittent nature of the operations. Therefore, special attention should be given to the design of these facilities.

Tank car and tank truck facilities should be located away from potential sources of heat, fire, and explosion. Equipment in these areas should also be protected from impact by vehicles and other moving equipment. An interlocked barrier system is commonly used to securely moor tank vehicles during transfer operations. Sufficient space should be available to avoid congestion of

vehicles or personnel during loading and unloading operations. Vehicles, especially trucks, should be able to move into and out of the area without reversing. High curbs around transfer areas and barriers around equipment should be provided to protect equipment from vehicle collisions.

When possible, the transfer of chlorine should be made with fixed rigid piping. In situations that require flexible hoses or tubes, precautions must be taken to ensure sound connections. The use of breakaway valves with autoclosing shutoff valves should also be considered to prevent pullaway type accidents. Avoiding cross contamination of chemical materials is also a key concern sometimes addressed by having dedicated pipe lines or hoses designed so that interconnections with inappropriate lines are not possible.

4.4 PROTECTION TECHNOLOGIES

This subsection describes two types of protection technologies for containment and neutralization: enclosures and scrubbers.

4.4.1 Enclosures

Enclosures refer to containment structures that capture any chlorine spilled or vented from storage or process equipment, thereby preventing immediate discharge of the chemical to the environment. The enclosures contain the spilled liquid or gas until it can be transferred to other containment, discharged at a controlled rate that would not be injurious to people or to the environment, or transferred at a controlled rate to scrubbers for neutralization.

Specially designed enclosures for either chlorine storage or process equipment do not appear to be widely used. Locating toxic operations in the open air has been mentioned favorably in the literature, as has the opposing idea that sometimes enclosures may be appropriate (1). A common design rationale for not having an enclosure where toxic materials are used is to

prevent the accumulation of toxic concentrations of a chemical within a work area. However, if the issue is protecting the community from accidental releases, then total enclosure may be appropriate. Enclosures should be equipped with continuous monitoring equipment and alarms. Alarms should sound whenever lethal or flammable concentrations are detected.

Care must be taken when an enclosure is built around pressuirzed equipment. It would not be practical to design an enclosure to withstand the pressures associated with the sudden failure of a pressurized vessel. An enclosure would probably fail as a result of the pressure created from such a release, creating an additional hazard. In these situations, it may be determined that an enclosure is not appropriate. If an enclosure is built around pressurized equipment, then it should be equipped with some type of explosion protection, such as rupture plates designed to fail before the entire structure fails.

The type of containment structures that appear to be suitable for chlorine are concrete block or concrete sheet buildings, or bunkers. Chlorine reactivity may preclude buildings of metal or wood. An enclosure would have a ventilation system designed to draw in air when the building is vented to a scrubber. The bottom section of a building used for stationary storage containers should be liquid tight to retain any liquid chlorine that might be spilled. Buildings around rail tank cars used for storage do not lend themselves to effective liquid containment; however, containment could be accomplished if the floor of the building was excavated several feet below the track level while the tracks are supported at grade in the center.

While enclosures for secondary containment of chlorine spills or releases are not widely used, thet can be considered as a possible protection for areas near especially sensitive receptors.

4.4.2 Scrubbers

Scrubbers are a traditional method for absorbing toxic gases from process streams. These devices can be used to control chlorine releases from vents and pressure relief discharges from storage equipment, process equipment, or secondary containment enclosures.

Chlorine discharges could be contacted with an aqueous scrubbing medium in any of several types of scrubbing devices. An alkaline solution is required to achieve effective absorption because absorption rates with water alone would require unreasonably high liquid-to-gas ratios. However, water scrubbing could be used in a make-shift scrubber in an emergency if an alkaline solution were not available. Table 4-5 presents typical alkaline solutions for an emergency scrubber.

Types of scrubbers that might be appropriate include spray towers, packed bed scrubbers, and venturis. Other types of special design might be suitable but complex internals subject to corrosion are not advisable. Whichever type of scrubber is selected, a key consideration for emergency systems is the design flow rate to be used. A conservative design would use the maximum rate that would be expected from an emergency.

A complete system includes the scrubber itself, a liquid feed system, and reagent makeup equipment. If such a system is used as protection against emergency releases, consideration must be given as to how it would be activated in time to respond to an emergency load. One approach used in some process facilities is to maintain a continuous circulation of scrubbing liquor through the system. This may be practical where the emergency scrubber also serves as a routine vent scrubber, but for many facilities this would not be practical and the scrubber system might be tied into a trip system that would turn it on when needed. Another approach is the drowning tank, where the chlorine vent is routed to the bottom of a large tank of uncirculating caustic. The drowning tank does not have the high contact efficiency of the other

TABLE 4-5. TYPICAL ALKALINE SOLUTION FOR CHLORINE SCRUBBING

Container Capacity (lb)	Caustic 100%, (lb)	Soda Water, (gal)	Soda (lb)	Ash Water, (gal)	Hydrated (lb)	Lime[a] Water (gal)
100	125	40	300	100	125	125
150	188	60	450	150	188	188
2,000	2,500	800	6,000	2,000	2,500	2,500

Source: Reference 5

[a]Note: Hydrated line solution must be continuously agitated to ensure aqueous mixture.

scrubber types; however, it can provide substantial capacity on demand as long as the back pressure of the hydrostatic head does not create a secondary hazard, by impeding an overpressure relief discharge, for example. In addition, precautions must be taken to prevent backflow of the scrubbing liquid through the lines to a chlorine containing vessel since explosions can occur. Such an event could occur if the scrubber overflowed.

When the scrubbing system must be activated by a trip system, venturi scrubbers have an advantage. A venturi scrubber can create its own draw of vapor by the flow of the scrubbing medium; thus, instead of turning on the flow of liquid and starting up a blower, as would be required in other types of scrubbing systems, a trip system need only turn on the flow of liquid to the scrubber.

4.5 MITIGATION TECHNOLOGIES

If, in spite of all precautions, a large release of chlorine occurs, the first priority is to rescue workers in the immediate vicinity of the accident and evacuate persons from downwind areas. The source of the release should be determined, and the leak should be stopped, if possible. The next primary concern is to reduce the effect the released chemical has on the plant and the surrounding community. Reducing the consequences of an accidental release of a hazardous chemical is referred to as mitigation. Mitigation technologies include such measures as physical barriers, water sprays and fogs, and foams where applicable. The purpose of a mitigation technique is to divert, limit, or disperse a chemical that has been spilled or released to the atmosphere to reduce the atmospheric concentration and the area affected by the chemical. The mitigation technology chosen for a particular chemical depends on its specific properties, including flammability, toxicity, reactivity, and those properties that determine its dispersion characteristics in the atmosphere.

If a release occurs from a pressurized chlorine storage tank above the boiling point, a quantity of liquid will immediately flash off as vapor, while

the remaining liquid will be cooled to the normal boiling point of -29.3°F. Heat transfer from the air and ground will result in further vaporization of the released liquid. Since the chlorine accidentally released from a refrigerated storage tank is already at or below its normal boiling point, a comparable quantity of vapor will not flash off, as with the pressurized release discussed above, but heat transfer from the environment will cause evaporation and the formation of a vapor cloud. It is therefore desirable to decrease the area available for heat transfer to a liquid spill, which in turn will decrease the rate of evaporation. Mitigation technologies used to reduce the rate of evaporation of a released liquified gas include secondary containment systems such as impounding basins and dikes.

4.5.1 Secondary Containment Systems

Specific types of secondary containment systems include excavated basins, natural basins, earth, steel, or concrete dikes, and high impounding walls. The type of containment system best suited for a particular storage tank or process unit will depend on the risk associated with an accidental release from that location. The inventory of chlorine and its proximity to other portions of the plant and to the community should be considered when selecting a secondary containment system, which should be able to contain spills, minimize damage to the facility and its surroundings, and minimize the potential for escalation of the event.

Secondary containment systems for chlorine storage facilities commonly consist of one of the following:

- An adequate drainage system underlying the storage vessels that terminates in an impounding basin having a capacity as large as the largest tank served; and

- A diked area, with a capacity as large as the largest tank served.

These measures are designed to prevent the accidental discharge of liquid chlorine from spreading to uncontrolled areas.

The most common type of containment system is a low wall dike surrounding one or more storage tanks. Generally, to reduce risk, no more than three tanks are enclosed within one diked area. Dike heights usually range from three to twelve feet, depending on the area available to achieve the required volumetric capacity. Dike walls should be liquid tight and able to withstand the hydrostatic pressure and temperature of a spill. Low wall dikes may be constructed of steel, concrete or earth. If earthen dikes are used, dike walls must be constructed and maintained to prevent leakage through the dike. Piping should be routed over dike walls, and penetrations through the walls should be avoided if possible. Vapor fences may be situated on top of the dikes to provide additional vapor containment. If there is more than one tank in the diked area, the tanks should be situated on berms above the maximum liquid level attainable in the impoundment.

A low-wall dike can effectively contain the liquid portion of an accidental release and keep the liquid from entering uncontrolled areas. By preventing the liquid from spreading, the low-wall dike can reduce the surface area of the spill. Reducing the surface area will reduce the rate of evaporation. The low-wall dike will partially protect the spill from wind, which can reduce the rate of evaporation. A dike with a vapor fence will provide extra protection from wind and will be even more effective in reducing the rate of evaporation.

A low-wall dike will not reduce the impact of a gaseous chlorine release. A dike also creates the potential for chlorine and trapped water to mix in the dike, which may accelerate the rate of evaporation and form highly corrosive hydrochloric and hydrochlorous acids. If materials that would react violently with chlorine are stored within the same diked area then the dike will increase the potential for mixing the materials in the event of a simultaneous leak. A dike also limits access to the tank during a spill.

A remote impounding basin is well-suited to storage systems where more than one tank is served and a relatively large site is available. The flow from a chlorine spill is directed to the basin by dikes and channels under the storage tanks, which are designed to minimize contact of the liquid with other tanks and surrounding facilities. Because of the high vapor pressure of chlorine, the trenches that lead to the remote impounding basin, as well as the basin itself, should be covered to reduce the rate of evaporation. Additionally, the impounding basin should be located near the tank area to minimize the amount of chlorine that evaporates as it travels to the basin.

This type of system has several advantages. The spilled liquid is removed from the immediate tank area, which allows access to the tank during the spill and reduces the probability that the spilled liquid will damage the tank, piping, electrical equipment, pumps or other equipment. In addition, the covered impoundment will reduce the rate of evaporation from the spill by protecting the spill from wind or heating from sunlight.

One limitation of a remote impounding basin is that there is still the potential for water or other incompatible materials to be trapped in the impoundment and mix with the incoming chlorine. Remote impounding basins do not reduce the impact of a gaseous chlorine release.

Although few authorities for chlorine facilities require them, high wall impoundments may be a good secondary containment choice for selected systems. Circumstances that may warrant their use include limited storage site area, the need to minimize vapor generation rates, and/or the tank must be protected from external hazards. Maximum vapor generation rates will generally be lower for a high wall impoundment than for low wall dikes or remote impoundments because of the reduced surface contact area. These rates can be further reduced with insulation on the wall and floor in the annular space. High impounding walls may be constructed of low temperature steel, reinforced concrete, or prestressed concrete. A weather shield may be provided between the tank and wall with the annular space remaining open to the atmosphere.

The available area surrounding the storage tank will dictate the minimum height of the wall. For high-wall impoundments, the walls may be designed with a volumetric capacity greater than that of the tank to provide vapor containment. Increasing the height of the wall also raises the elevation of any released vapor.

One disadvantage of these dikes is that the high walls around a tank may hinder routine external observation. Furthermore, the closer the wall is to the tank, the more difficult it becomes to approach the tank for inspection and maintenance. As with low-wall dikes, piping should be routed over the wall if possible. The closeness of the wall to the tank may necessitate placement of the pump outside of the wall, in which case the outlet (suction) line will have to pass through the wall. In such a situation, a low dike encompassing the pipe penetration and pump may be provided, or a low dike may be placed around the entire wall.

One further type of secondary containment system is structurally integrated with the primary system to form a vapor-tight enclosure around the primary container. Many types of arrangements are possible. A double-walled tank is an example of such an enclosure. These systems may be considered where protection of the primary container and containment of vapor for events not involving foundation or wall penetration failure are of greatest concern. Drawbacks of an integrated system are the greater complexity of the structure, the difficulty of access to certain components, and the fact that complete vapor containment cannot be guaranteed for all potential events.

Provision should be made for drainage of rainwater from diked areas. This will involve the use of sumps and separate drainage pumps, since direct drainage to stormwater sewers would presumably allow any spilled chlorine to follow the same route. Alternately, a sloped rain hood may be used over the diked area that could also serve to direct the rising vapors to a single release point (22). The ground within the enclosure should be graded to cause the spilled liquid to accumulate at one side or in one corner. This will help

minimize the area of ground which the liquid is exposed to and from which it may gain heat. In areas where it is critical to minimize vapor generation, surface insulation may be used in the diked area to further reduce heat transfer from the environment to the spilled liquid. The floor of an impoundment should be sealed with a clay blanket to prevent the chlorine from seeping into the ground; percolation into the ground causes the ground to cool more quickly, increasing the vapor generation rate. Absorption of the chlorine into water in the soil would also release additional heat.

4.5.2 Flotation Devices and Foams

This subsection discusses the applicability, availability, and effectiveness of additional mitigation technologies used to reduce the surface area of spilled chlorine, thereby minimizing the amount of toxic vapor released to the surrounding environment.

Flotation Devices--

The efficiency of placing an impermeable flotation device over a spilled chemical is nearly 100 percent. However, being able to use such devices requires that they be acquired in advance of a spill and stored until needed. In addition, deployment may be difficult in all but small spills.

Although such devices are potentially effective, no system is currently available for mitigating chlorine spills. The primary deterrent to their use is the cost associated with material and dispersal equipment. Such a system would require the dispersal of a minimum of 280 particles per square foot of spill surface (23). Based on 1986 prices, material costs would be approximately $100 per square foot, with dispersal equipment costs running 100 times this cost (23).

Foams--

Water should not be used to dilute chlorine spills. Chlorine is only slightly soluble in water and a large quantity would be required for dilution.

The addition of water to a liquid chlorine spill would significantly increase the rate of heat transfer to the spill and result in increased vapor generation rates. In addition, dilution of chlorine with water results in the formation of highly corrosive hydrochloric and hydrochlorous acids. As such, the Chlorine Institute states that water should never be used on a chlorine leak since water will make the leak worse (5). A water-based foam cover provides an alternative means of diluting the chlorine.

The use of foams in vapor hazard control has been demonstrated for a broad range of volatile chemicals. Unfortunately, it is difficult to accurately quantify the benefits of foam systems because the effects will vary with the chemical spilled, foam type, spill size, and atmospheric conditions. With regard to liquified gases, it has been found that with some materials, foams have a net positive effect, but with others, foams may exaggerate the hazard.

Several studies of the effect of foam on chlorine conducted in the past have given mixed results (24,25). For the current grades of commercially available foam systems (i.e., protein-derived material and surfactant-based concentrates), application to liquid chlorine results in rapid destruction of the foam and a gross exaggeration of the boil-off rate (24,26). This effect may last through several successive applications, depending on the type of foam, the expansion, and the rate of application.

As foam is applied, the interaction of the chlorine and the collapsing foam results in the formation of a layer of ice and chlorine hydrate that tends to float on the chlorine surface (26). As the foam application continues, this layer eventually becomes continuous and a foam covering can then be built on top of the chlorine surface. When this occurs, a reduction in the downwind concentration can be achieved (26).

Sufficient data are not presently available to define the variables needed to implement such a system (i.e., best foam type, expansion type,

application rate, and duration of application). Based on preliminary research studies, medium expansion foams (300 to 350:1) appear to work best, but low expansion foams have also shown some benefit (26). The results of a laboratory test program conducted by the Mine Safety Appliance (MSA) Research Corporation (24) to evaluate the applicability and effectiveness of various foams for various hazardous chemicals including chlorine is presented in Table 4-6 (24).

Regardless of the type of foam used, the slower the drainage rate of the foam, the better its performance will be. A slow draining foam will collapse more slowly. The initial cost for a slow draining foam may be higher than for other foams, but a cost effective system will be realized in superior performance.

Even if the vaporization rate of chlorine is substantially reduced within a short time after a spill, a vapor cloud will still be formed that poses a serious threat downwind. Dispersion and/or removal of the chlorine vapor in the atmosphere is the subject of the following section.

4.5.3 Mitigation Techniques for Chlorine Vapor

The extent to which the escaped chlorine vapor can be removed or dispersed in a timely manner will be a function of the quantity of vapor released, the ambient conditions, and the physical characteristics of the vapor cloud. The behavior and characteristics of the chlorine cloud will depend on a number of factors, including the physical state of the chlorine before its release, the location of the release, and the atmospheric and environmental conditions. Many possibilities exist concerning the shape and motion of the vapor cloud, and a number of predictive models of dispersion have been developed. As a result of the higher specific gravity of pure chlorine, large accidental releases of chlorine will often result in the formation of chlorine-air mixtures that are denser than the surrounding atmosphere. This

TABLE 4-6. FOAM CAPABILITIES TO SUPPRESS OR MINIMIZE THE RELEASE OF TOXIC VAPORS FROM A CHLORINE SPILL

Foam Type	Capability
Low-expansion surfactant	Acceptable in some situations
High-expansion surfactant	Acceptable in some situations
Protein	Acceptable in some situations
Fluoroprotein	Acceptable in some situations
Alcohol	Unsuitable
Aqueous film-forming foams (AFFF)	Unsuitable

Source: Reference 24

type of vapor cloud is especially hazardous, because it will spread laterally and remain close to the ground.

Water sprays or fogs can be used to disperse as well as remove toxic vapors from the air. The low solubility of chlorine in water, however, limits the effectiveness of such systems for chlorine removal from the air. An alternative is to use a mild aqueous alkaline spray system such as an ammonia-injected water spray system that would act as a neutralizing agent for any acid formed in the process. Although such systems are not widely used for the mitigation of chlorine vapor, they are used for other similar toxic chemicals (27).

The spray medium is typically applied to the vapor cloud by hand-held hoses and/or stationary water-spray barriers. Important factors relating to the effectiveness of sprays systems are the distance of the nozzles from the point of release, the fog pattern, nozzle flow rate, pressure, and nozzle rotation. If water sprays are used to mitigate chlorine vapors from a diked area containing spilled liquid chlorine, great care must be taken not to direct water into the liquid chlorine itself.

Several techniques have also been developed to effectively disperse toxic vapor resulting from major leaks in piping and equipment. One such technique has been developed by Beresford (28). Although such systems has not been used to mitigate chlorine vapor, they have been effectively used for other toxic chemicals of similar nature (28). In addition, such techniques are not applicable to catastrophic failures of equipment.

The method consists of coarse water sprays discharging upwards from flat fan sprays and wide-angled spray monitors arranged so that a vent or chimney effect is created to completely surround the toxic vapor. Results have shown that the high velocity water droplets induce large volumes of air at ground level as the water discharges upwards (28). The air is caused to move upwards through the chimney formed by the sprays. As the air moves over the ground,

the heavier-than-air toxic gas is diluted and pushed up and out of the top of the chimney where it disperses safely. Design details are presented in Beresford (28). Both types of spray methods are incorporated into the design since the flat-fan sprays effectively stop the lateral spread of vapor and the monitors provide the required air movement for dilution and disposal.

Another means of dispersing a vapor cloud are large fans or blowers that direct the vapor away from populated or other sensitive areas. However, this method is feasible only in very calm weather and in sheltered areas; it would not be effective in any wind and would be difficult to control if the release occupies a large open area. A large, mechanical blower would also be required, which lowers the reliability of this mitigation technique.

In general, techniques used to disperse or control vapor emissions should emphasize simplicity and reliability. In addition to the mitigation techniques discussed above, physical barriers such as buildings and rows of trees will help to contain the vapor cloud and control its movement.

4.6 OPERATION AND MAINTENANCE PRACTICES

Accidental releases of toxic materials result not only from deficiencies in process design or equipment but also from operation deficiencies. Thus safe operation of plants using chlorine requires competent and experienced managers and staff in addition to a well-considered and fully understood system of work.

Employees should be trained about the important aspects of handling chlorine, including: proper handling and storing procedures, hazards resulting from improper use and handling, prevention of spills, cleanup procedures, maintenance procedures and emergency procedures. Well-defined and planned out practices and procedures can minimize the possibility of an accidental release or its magnitude, if it should occur.

Proper preventive maintenance and modification programs should be a normal part of plant operation and design procedures to reduce the chances for an accidental release. Maintenance should be based on a priority system to ensure that the most critical equipment is taken care of first. Strict procedures should apply to process modifications to ensure that modifications do not create an unintended hazard. Inspections and nondestructive testing of vessels, piping, and machinery should be conducted periodically to detect small flaws that could eventually lead to a major release.

Numerous other special operating and maintenance practices apply where chlorine is used. For example, pH readings of cooling water and condensate are commonly taken several times a day to detect internal leaks. To prevent corrosion, the chlorine is analyzed for water several times a week (10). In addition, cutting torches or other high temperature devices should be used with the greatest care since chlorine will burn steel if heated to a high enough temperature. The piece of equipment should be empty and isolated from other equipment when such work is done.

4.7 CONTROL EFFECTIVENESS

It is difficult to quantify the effectiveness of preventive and protective measures in reducing the probability and magnitude of accidental releases. Preventive measures, which may involve numerous combinations of process design, equipment design, and operational measures, are especially difficult to quantify because they reduce the probability of a release rather than a physical quantity of chemical. Since protective measures are more analogous to traditional pollution control technologies, they may be easier to quantify in terms of their efficiency in reducing the quantity of a releases chemical.

Preventive measures reduce the probability of an accidental release by increasing the reliability of process systems operations and equipment. Control effectiveness can thus be expressed for both of the qualitative improvements achieved and quantitative improvements as probabilities. Table

4-7 summarizes what appear to be major design, equipment, and operational measures applicable to the primary hazards identified for the chlorine applications in the SCAQMD. The items listed in Table 4-7 are for illustration only, and do not necessarily represent a satisfactory control option for all cases. These control options appear to reduce the risk associated with an accidental release when viewed from a broad perspective. However, there are undoubtedly specific cases where these control options will not be appropriate. Each case must be evaluated individually.

4.8 ILLUSTRATIVE COST ESTIMATES FOR CONTROLS

This section presents cost estimates for different levels of control and for specific release prevention and protection measures that might be found in the SCAQMD for chlorine storage and process facilities.

4.8.1 Prevention and Protection Measures

Preventive measures reduce the probability of an accidental release from a process or storage facility by increasing the reliability of both process systems operations and equipment. Along with an increase in the reliability of a system is an increase in the capital and annual costs associated with incorporating prevention and protection measures into a system. Table 4-8 presents costs for some of the major design, equipment, and operational measures applicable to the primary hazards identified in Table 4-7 for the chlorine applications in the SCAQMD.

4.8.2 Levels of Control

The prevention of accidental releases relies on a combination of technological, administrative, and operational practices as they apply to the design, construction, and operation of facilities where hazardous chemicals are used and stored. At a minimum, equipment and procedures should be in accordance with applicable codes, standards, and regulations; however,

TABLE 4-7. EXAMPLES OF MAJOR PREVENTION AND PROTECTION MEASURES FOR CHLORINE RELEASES

Hazard Area	Prevention/Protection
External fire	Water sprays to cool exposed chlorine storage vessels; siting away from flammables; refrigeration systems; heat shield
Line, pipe, and valve failure	Replacement of copper with Monel in small lines; more frequent inspections and maintenance
Flexible connection failures	Minimized use; higher quality components; operator training in proper assembly
Fusible plug failure	Inspection/certification; storage in a containment building
Human error	Increased training and supervision; use of checklists; use of automatic systems
Container failure	Adequate pressure relief; inspection and maintenance; corrosion monitoring; siting away from fire and mechanical damage
Vehicular collisions	Location; physical barriers; warning signs; training
Water intrusion	Pad gas drying; backflow prevention; equipment purging with dry gas
Corrosion	Inspections, maintenance, and corrosion monitoring
Excess chlorine rates	Enhanced flow control; limited over-design of feed systems; fail-shut control valves
Overheated reactor	Redundant temperature sensing and alarms; interlocked chlorine feed shut-off; pH control for bleach reactor

(Continued)

TABLE 4-7 (Continued)

Hazard Area	Prevention/Protection
Heating media flow control	Enhanced flow control; redundant temperature sensing and alarm
Overpressure	Enhanced pressure relief (non-isolatable, adequate-sized, no discharge restrictions, safe discharge point)
Direct relief discharges to atmosphere	Emergency scrubber system; tank enclosures
Major tank or line rupture in storage	Diking; enclosure with scrubber; corrosion monitoring; overpressure protection; siting away from flammables and mechanical damage; inspection and non-destructive testing
Failure of mixing in bleach reaction	Interlock chlorine feed shut-off on loss of mixing power

TABLE 4-8. ESTIMATED TYPICAL COSTS OF SOME PREVENTION AND PROTECTION MEASURES FOR CHLORINE RELEASES[a]

Prevention/Protection Measure	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Replacement of copper lines with Monel®	150-200	20-25
Pressure relief		
- relief valve	1,000-2,000	120-250
- rupture disk	1,000-1,200	120-150
Physical barriers		
- curbing	750-1,000	90-120
- 3 ft. retaining wall	1,500-2,000	175-250
Flow control loop	4,000-6,000	500-750
Temperature sensor	250-400	30-50
pH control	7,500-10,000	900-1,300
Interlock system for feed shut-off	1,500-2,000	175-250
Alarm system	250-500	30-75
Diking		
- 3 ft high	1,200-1,500	150-175
- top of tank height, 10 ft.	7,000-7,500	850-900
Corrosion monitoring[b]		200-400
Increased inspections and maintenance[c]		250-500

[a] Based on a 10,000 gallon fixed chlorine storage tank system and a 2,000 gallon continuous sodium hypochlorite bleach reactor system.

[b] Based on 10-20 hr @ $20/hr.

[c] Based on 12.5-25 hr @ $20/hr.

additional measures can be taken to provide extra protection against an accidental release.

The levels of control concept provides a means of assigning costs to increased levels of prevention and protection. The minimum level is referred to as the "Baseline" system. This system consists of the elements required for normal safe operation and basic prevention of an accidental release of hazardous material.

The second level of control is "Level 1". "Level 1" includes the baseline system with added modifications, such as improved materials of construction, additional controls, and generally more extensive release prevention measures. The costs associated with this level are higher than the baseline system costs.

The third level of control is "Level 2". This system incorporates both the "Baseline" and "Level 1" systems with additional modifications, such as alarm and interlock systems designed specifically for preventing an accidental release. The extra accidental release prevention measures incorporated into "Level 2" are reflected in its cost, which is much higher than that of the baseline system.

When comparing the costs of the various levels of control, it is important to realize that higher costs do not necessarily imply improved safety. The measures must be applied correctly. Inappropriate modifications or add-ons may not make a system safer. Each added control option increases the complexity of a system. In some cases the hazards associated with the increased complexity may outweigh the benefits derived from the particular control option. Proper design and construction along with proper operational practices are needed to assure safe operation.

These estimates are for illustrative purposes only. It is doubtful that any specific installation would find all of the control options listed in

these tables appropriate. An actual system is likely to incorporate some items from each of the levels of control and also some control options not listed here. The purpose of these estimates is to illustrate the relationship between cost and control, not to provide an equipment check list.

Levels-of-control cost estimates were prepared for a 42 ton fixed chlorine storage tank system with a 10,000 gal capacity and a sodium hypochlorite bleach batch reactor system with 2,000 gal capacity. These systems are representative of storage and process facilities that might be found in the SCAQMD.

4.8.3 Cost Summaries

Table 4-9 summarizes the total capital and annual costs for each of the three levels of controls for the chlorine storage system and the chlorine bleach reactor system. The costs presented correspond to the systems described in Tables 4-10 and 4-11. Each of the level costs include the cost of the basic system plus any added controls. Specific cost information and breakdown for each level of control for both the storage and process facilities are presented in Tables 4-12 through 4-17.

4.8.4 Equipment Specifications and Detailed Costs

Equipment specifications and details of the capital cost estimates for the chlorine storage and the chlorine bleach reactor systems are presented in Tables 4-18 through 4-25.

4.8.5 Methodology

Format for Presenting Cost Estimates--

Tables are provided for control schemes associated with storage and process facilities for chlorine showing capital, operating, and total annual costs. The tables are broken down into subsections comprising vessels, piping

TABLE 4-9. SUMMARY COST ESTIMATES OF POTENTIAL LEVELS OF CONTROLS FOR CHLORINE STORAGE TANK AND HYPOCHLORITE BLEACH REACTOR

	Level of Control	Total Capital Cost (1986 $)	Total Annual Cost (1986 $/yr)
Chlorine Storage Tank; 60 Ton Fixed Chlorine Tank with 10,000 Gallon Capacity	Baseline	208,000	25,000
	Level No. 1	510,000	60,000
	Level No. 2	783,000	92,000
Continuous Sodium Hypochlorite Bleach Reactor System with 2,000 Gallon Chlorination Tank	Baseline	105,000	13,000
	Level No. 1	123,000	16,000
	Level No. 2	130,000	17,000

TABLE 4-10. EXAMPLE OF LEVELS OF CONTROL FOR CHLORINE STORAGE TANK

Process: 60 ton fixed chlorine storage tank 10,000 gal
10,000 gal

Controls	Baseline	Level No. 1	Level No. 2
Flow:	Single checkvalve on tankprocess feed line.	Add second check valve.	Add a reduced-pressure device[a] with internal air gap and relief vent to scrubber.
Temperature:	None	None	Add temperature indicator.
Pressure:	Single pressure relief valve, vent to atmosphere, provide local pressure indicator.	Add second relief valve, secure non-isolatable installation; vent to scrubber.	Add rupture disks under relief valves; provide local pressure indication on space between disk and valves; vent to scrubber.
Quantity:	Local level indicator.	Add remote level indicator.	Add level alarm. Add high-low level interlock shut-off for both inlet and outlet lines.
Location:	Away from traffic, flammables, and other hazardous processes.	Away from traffic, flammables, and other hazardous processes.	Away from traffic flammables, and other hazardous processes.
Materials of Construction:	Carbon steel.	Carbon steel with increased corrosion allowances. (1/8 inch)	Kynar® lined carbon steel.

(continued)

[a]The examples in this table are appropriate for many, but not all applications. This is only an exemplary system. Design must be suited to fit the specific service.

[b]A reduced pressure device is a modified double check valve.

TABLE 4-10 (Continued)

Process: 60 ton fixed chlorine storage tank
10,000 gal

Controls	Baseline	Level No. 1	Level No. 2
Vessel:	Tank pressure specification 225 psig.	Tank pressure specification 300 psig.	Tank pressure specification 375 psig.
Piping:	Sch. 80 carbon steel.	Sch. 80 Kynar® lined carbon steel.	Sch. 80 Monel®.
Process Machinery:	Centrifugal pump, carbon steel, stuffing box seal.	Centrifugal pump, Kynar® lined steel, double mechanical seal.	Magnetically-coupled centrifugal pump, Kynar® lined steel.
Enclosures:	None	Steel building.	Concrete building.
Diking:	None	3 ft. high dike.	Top of tank height, 10 ft.
Scrubbers:	None	Water scrubber for relief and building vents.	Alkaline scrubber for relief and building vents.
Mitigation:	None	Water sprays.	Alkaline water sprays and barriers.

TABLE 4-11. EXAMPLE OF LEVELS OF CONTROL FOR CHLORINE BLEACH REACTOR[a]
Process: Continuous Sodium Hypochlorite Production

Controls	Baseline	Tier #1	Tier #2
Process:	Adequate cooling system.	Limited over-design of feed systems.	Interlock systems on feed systems.
Temperature:	Local temperature indicator.	Add redundant sensing and alarm. Add remote indicator.	Add temperature switch to shut off Cl_2 feed when temp. rises above a certain set point.
Pressure:	Single pressure relief valve. Vent to atmosphere. Expansion tank on chlorine feed line.	Add local pressure indicator on tank. Vent relief valve to scrubber.	Add rupture disk and provide local pressure indication on space between disk and valve.
Flow:	Local flow indicator on Cl_2 feed line.	Add remote indicator.	Add flow switch to shut off chlorine feed on loss of cooling medium.
Quantity:	None	None	Level alarm
Mixing:	Provide adequate mixing.	Add alarm on loss of recirculating pump.	Interlock chlorine feed on loss of mixing.
Composition:	pH monitoring and control.	Same	Same

(Continued)

[a]The examples in this table are appropriate for many, but not all applications. This is only an exemplary system. Design must be suited to fit the specific service.

TABLE 4-11 (Continued)

Controls	Baseline	Tier #1	Tier #2
Material of Construction:	Fiberglass-reinforced plastic - epoxy lined.	Same	Same
Vessel:	Atmospheric tank.	Same	Same
Piping:	Sch. 40 CPVC for bleach solutions.	Sch. 80 CPVC for bleach solutions.	Same
Process Machinery:	Centrifugal pump, Hastelloy C construction, stuffing box.	Same	Same
Enclosure:	None	Steel building.	Concrete building.
Diking:	None	Curbing around process area.	Retaining wall around process area.

TABLE 4-12. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH BASELINE CHLORINE STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Storage tank	170,000	20,000
Expansion tanks (3)	6,500	760
Piping and Valves:		
Pipework	2,300	270
Expansion loop	160	20
Check valve	280	35
Ball valves (5)	3,200	370
Excess flow valves (2)	500	60
Angle valves (2)	2,100	250
Relief valve	2,000	230
Process Machinery:		
Centrifugal pump	4,000	470
Instrumentation:		
Pressure gauges (4)	1,500	180
Load cell	16,000	1,800
Procedures and Practices:		
Visual tank inspection (external)		15
Visual tank inspection (internal)		60
Relief valve inspection		15
Piping inspection		300
Piping maintenance		120
Valve inspection		30
Valve maintenance		350
Total Costs	208,000	25,000

TABLE 4-13. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 1 CHLORINE STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Storage tank	220,000	26,000
Expansion tanks (3)	6,500	760
Piping and Valves:		
Pipework	5,900	690
Expansion loop	160	20
Check valve	570	65
Ball valves (5)	3,200	370
Excess flow valves (2)	500	60
Angle valves (2)	2,100	250
Relief valve	4,000	470
Process Machinery:		
Centrifugal pump	6,400	750
Instrumentation:		
Pressure gauges (4)	1,500	180
Flow indicator	3,700	430
Load cell	16,000	1,800
Remote level indicator	1,900	220
Enclosures:		
Steel building	10,000	1,200
Scrubbers:		
Water scrubber	226,000	26,000
Diking:		
3ft high concrete diking	1,400	160

(Continued)

TABLE 4-13 (Continued)

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Procedures and Practices:		
Visual tank inspection (external)		15
Visual tank inspection (internal)		60
Relief valve inspection		30
Piping inspection		300
Piping maintenance		120
Valve inspection		35
Valve maintenance		400
Total Costs	510,000	60,000

TABLE 4-14. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 2 CHLORINE STORAGE SYSTEM

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Storage tank	411,000	48,000
Expansion tanks (3)	6,500	760
Piping and Valves:		
Pipework	12,000	1,500
Expansion loop	160	20
Reduced pressure device	1,500	180
Ball valves (5)	3,200	370
Excess flow valves (2)	500	60
Angle valves (2)	2,100	250
Relief valve	4,000	470
Rupture disks (2)	1,100	130
Process Machinery:		
Centrifugal pump	8,500	1,000
Instrumentation:		
Temperature indicator	2,200	260
Pressure gauges (6)	2,200	260
Flow indicator	3,700	430
Load cell	16,000	1,800
Remote level indicator	1,900	220
Level alarm	380	45
High-low level shutoff	1,900	220
Enclosures:		
Concrete building	19,000	2,200
Scrubbers:		
Alkaline scrubber	280,000	33,000
Diking:		
10 ft high concrete diking	7,600	880

(Continued)

TABLE 4-14 (Continued)

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Procedures and Practices:		
Visual tank inspection (external)		15
Visual tank inspection (internal)		60
Relief valve inspection		50
Piping inspection		300
Piping maintenance		120
Valve inspection		35
Valve maintenance		400
Total Costs	786,000	92,000

TABLE 4-15. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH BASELINE CONTINUOUS SODIUM HYPOCHLORITE PRODUCTION

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Chlorination tank	35,000	4,100
Expansion tank	2,200	260
Piping and Valves:		
Pipework	7,300	870
Ball and globe valves (8)	1,800	220
Relief valve	2,000	235
Process Machinery:		
Centrifugal pumps (2)	21,000	2,500
Instrumentation:		
Pressure gauges (3)	1,110	130
Temperature control		
- Controller	1,800	220
- Sensor	180	20
- Control valve	2,700	330
pH Control		
- Controller	1,800	220
- pH detector	7,300	870
- Control valve	2,700	330
Composition control		
- Controller	1,800	220
- ORP sensing cell	7,300	870
- control valve	3,600	430
Flow control		
- Controller	1,800	220
- Flowmeter	2,300	280
- Control valve	2,700	330

(Continued)

TABLE 4-15 (Continued)

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Procedures and Practices:		
Visual tank inspection (external)		15
Visual tank inspection (internal)		60
Relief valve inspection		15
Piping inspection		600
Piping maintenance		250
Valve inspection		40
Valve maintenance		400
Total Costs	105,000	13,000

TABLE 4-16. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 1 CONTINUOUS SODIUM HYPOCHLORITE PRODUCTION

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Chlorination tank	34,000	4,100
Expansion tank	2,200	260
Piping and Valves:		
Pipework	9,100	1,100
Ball and globe valves (8)	1,800	220
Relief valve	2,000	230
Process Machinery:		
Centrifugal pumps (2)	21,000	2,500
Instrumentation:		
Pressure gauges (4)	1,400	180
Flow indicator	3,600	430
Local temp. indicator	2,200	260
Temperature alarm	360	45
Temperature control		
- Controller	1,800	220
- Sensor	360	45
- Control valve	2,700	330
pH Control		
- Controller	1,800	220
- pH detector	7,300	870
- Control valve	2,700	330
Composition control		
- Controller	1,800	220
- ORP sensing cell	7,300	870
- Control valve	3,600	430

(Continued)

TABLE 4-16 (Continued)

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Flow control		
- Controller	1,800	220
- Flowmeter	2,300	280
- Control valve	2,700	330
Diking:		
Curbing around reactor	910	110
Enclosure:		
Steel building	8,300	1,000
Procedures and Practices:		
Visual tank inspection (external)		15
Visual tank inspection (internal)		60
Relief valve inspection		15
Piping inspection		600
Piping maintenance		250
Valve inspection		40
Valve maintenance		400
Total Costs	123,000	16,000

TABLE 4-17. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 2 CONTINUOUS SODIUM HYPOCHLORITE PRODUCTION

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Vessels:		
Chlorination tank	34,000	4,100
Expansion tank	2,200	260
Piping and Valves:		
Pipework	9,100	1,100
Ball and globe valves (8)	1,800	220
Relief valve	2,000	230
Process Machinery:		
Centrifugal pumps (2)	21,000	2,500
Instrumentation:		
Level alarm	360	45
Mixing interlock system	1,800	220
Pressure gauges (4)	1,400	180
Flow interlock system	1,800	220
Flow indicator	3,600	430
Flow control		
- Controller	1,800	220
- Flowmeter	2,300	280
- Control valve	2,700	330
Local temp. indicator	2,200	260
Temperature alarm	360	45
Temperature control		
- Controller	1,800	220
- Sensors (2)	360	45
- Control valve	2,700	330
pH Control		
- Controller	1,800	229
- pH detector	7,300	870
- Control valve	2,700	330
Composition control		
- Controller	1,800	220
- ORP sensing cell	7,300	870
- control valve	3,600	430

(Continued)

TABLE 4-17 (Continued)

	Capital Cost (1986 $)	Annual Cost (1986 $/yr)
Diking:		
3 ft retaining wall	1,600	200
Enclosure:		
Concrete building	11,000	1,300
Procedures and Practices:		
Visual tank inspection (external)		15
Visual tank inspection (internal)		60
Relief valve inspection		20
Piping inspection		600
Piping maintenance		120
Valve inspection		40
Valve maintenance		400
Total Costs	130,000	17,000

TABLE 4-18. EQUIPMENT SPECIFICATIONS ASSOCIATED WITH CHLORINE STORAGE SYSTEM

Equipment Item	Equipment Specification	Reference
Vessels:		
Storage tank	Baseline: 10,000 gal. carbon steel, 225 psig rating Level 1: 10,000 gal. carbon steel with 1/8 in. corrosion protection, 300 psig rating Level 2: 10,000 gal. Kynar® lined carbon steel, 375 psig rating	29,30,31,32
Expansion tank	Standard carbon steel pressure vessel with rupture disk and pressure gauge	29,30
Piping and Valves:		
Pipework	Baseline: 1 in. schedule 80 carbon steel Level 1: 1 in. schedule 80 Kynar® lined carbon steel Level 2: 1 in. schedule 80 Monel®	33
Check valve	1 in. vertical left check valve, Monel® trim	30,34
Ball valve	300 lb., screwed, cast steel body, Monel® ball and stem, reinforced PTFE seat, PTFE seals	29,30,34
Excess flow valve	1.25 in. standard valve	30
Angle valve	1 in. carbon steel, cast	35
Relief valve	1 in. x 2 in., class 300 inlet and outlet flange, angle body, closed bonnet with screwed cap, carbon steel body, Monel® trim	30

(Continued)

TABLE 4-18 (Continued)

Equipment Item	Equipment Specification	Reference
Enclosure:		
Building	Level 1: 26 gauge steel walls and roof, door, ventilation system Level 2: 10 in. concrete walls, 26 gauge steel roof, door	35
Scrubber:	Level 1: Spray tower, Monel® construction, water sprays, 6 ft. x 18 ft. Level 2: Spray tower, Monel® construction, alkaline sprays	41
Diking:	Level 1: 6 in. concrete walls, high Level 2: 10 in. concrete walls, top of tank height	35

TABLE 4-19. MATERIAL AND LABOR COSTS ASSOCIATED WITH BASELINE CHLORINE STORAGE SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Vessels:					
Storage tank	79,000	35,000	114,000	40,000	170,000
Expansion tanks (3)	3,500	880	4,380	1,500	6,500
Piping and Valves:					
Pipework	550	1,000	1,550	542	2,300
Expansion loop	75	35	110	40	160
Check valves	160	30	190	65	280
Ball valves (5)	2,000	150	2,150	750	3,200
Excess flow valves (2)	300	40	340	120	500
Angle valves (2)	1,400	40	1,440	500	2,100
Relief valve	1,300	50	1,350	470	2,000
Process Machinery:					
Centrifugal pump	1,900	800	2,700	950	4,000
Instrumentation:					
Pressure gauges (4)	800	200	1,000	350	1,500
Load cell	8,400	2,100	10,500	3,700	16,000
Total Costs	99,000	41,000	140,000	49,000	208,000

TABLE 4-20. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 1 CHLORINE STORAGE SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Vessels:					
Storage tank	102,000	46,000	148,000	52,000	220,000
Expansion tanks (3)	3,500	880	4,380	1,500	6,500
Piping and Valves:					
Pipework	3,300	680	3,980	1,400	5,900
Expansion loop	75	35	110	40	160
Check valves	320	60	380	140	570
Ball valves (5)	2,000	150	2,150	750	3,200
Excess flow valves (2)	300	40	340	120	500
Angle valves (2)	1,400	40	1,440	500	2,100
Relief valve	2,600	100	2,700	950	4,000
Process Machinery:					
Centrifugal pump	3,000	1,300	4,300	1,500	6,400
Instrumentation:					
Pressure gauges (4)	800	200	1,000	350	1,500
Flow indicator	2,000	500	2,500	880	3,700
Load cell	8,400	2,100	10,500	3,700	16,000
Remote level indicator	1,000	250	1,250	440	1,900

(Continued)

TABLE 4-20 (Continued)

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Enclosures:					
Steel building	4,600	2,300	6,900	2,400	10,000
Scrubbers:					
Water scrubber	105,000	47,000	152,000	53,000	226,000
Diking:					
3 ft high concrete diking	390	520	910	320	1,400
Total Costs	241,000	102,000	343,000	120,000	510,000

TABLE 4-21. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 2 CHLORINE STORAGE SYSTEM

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Vessels:					
Storage tank	191,000	86,000	277,000	97,000	411,000
Expansion tanks (3)	3,500	880	4,380	1,500	6,500
Piping and Valves:					
Pipework	4,800	3,500	8,300	2,900	12,000
Expansion loop	75	35	110	40	160
Reduced pressure device	800	200	1,000	350	1,500
Ball valves (5)	2,000	150	2,150	750	3,200
Excess flow valves (2)	300	40	340	120	500
Angle valves (2)	1,400	40	1,440	500	2,100
Relief valve	2,600	100	2,700	950	4,000
Rupture disks (2)	650	75	725	260	1,100
Process Machinery:					
Centrifugal pump	4,000	1,700	5,700	2,000	8,500
Instrumentation:					
Temperature indicator	1,200	300	1,500	530	2,200
Pressure gauges (6)	1,200	300	1,500	530	2,200
Flow indicator	2,000	500	2,500	880	3,700
Load cell	8,400	2,100	10,500	3,700	16,000
Remote level indicator	1,000	250	1,250	440	1,900
Level alarm	200	50	250	90	380
High-low level shutoff	1,000	250	1,250	440	1,900

(Continued)

TABLE 4-21 (Continued)

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Enclosures:					
Concrete building	6,100	6,600	12,700	4,400	19,000
Scrubbers:					
Alkaline scrubber	130,000	59,000	189,000	66,000	280,000
Diking:					
10 ft high concrete dike	2,200	2,900	5,100	1,800	7,600
Total Costs	365,000	165,000	529,000	186,000	786,000

TABLE 4-22. EQUIPMENT SPECIFICATIONS ASSOCIATED WITH CHLORINE BLEACH REACTOR SYSTEM

Equipment Item	Equipment Specification	Reference
Vessels:		
Chlorination tank	2,000 gal. fiber-reinforced plastic tank	26
Expansion tank	Standard carbon steel pressure vessel with rupture disk and pressure gauge	17,18
Piping and Valves:		
Pipework	Baseline: 1 in. schedule 80 Monel®, chlorine feed line 2 in. schedule 40 CPVC for bleach solutions Levels 1 & 2: 2 in. schedule 80 CPVC for bleach solutions	18,21
Ball valves	300 lb., screwed, cast steel body, Monel® ball and trim,	17,18,22
Glove valves	Class 150, flanged, cast steel, Monel® disk and seat	17,18,22
Relief valve	1 in. x 2 in., class 300 inlet and outlet flange, angle body, closed bonnet with screwed cap, carbon steel body, Monel® trim	18
Process Machinery:		
Centrifugal pump	Hastelloy C construction, stuffing box	26
Instrumentation:		
Level alarm	Indicating and audible alarm	18,23,29
Interlock system	Solenoid valve, switch, and relay system	17,18,23,27

(Continued)

TABLE 4-22 (Continued)

Equipment Item	Equipment Specification	Reference
Pressure gauge	Diaphragm sealed, Monel® diaphragm, 0-500 psi	17,18,27
Flowmeter	D/P cell and transmitter and associated flow indicator	17,18,27
Control valve	1 in. and 2 in. globe valves, Monel® trim	17,31
Controller	Standard PID controller	17,32,33
Temperature indicator	Thermocouple, thermowell, and electronic indicator	17,18,27
Temp. sensor	Thermocouple and associated thermowell	17,18,27
pH detector	Electrode, electrode chamber, amplifier-transducer and indicator	17,28
ORP sensing cell	Standard calomel oxidation-reduction potential sensing cell	17,28
Diking:	Level 1: 6 in. concrete curbing Level 2: 3 ft. high retaining wall	23
Enclosure:	Level 1: 26 gauge steel walls and roof, door, ventilation system Level 2: 10 in. concrete walls, 26 gauge steel roof, door	23

TABLE 4-23. MATERIAL AND LABOR COSTS ASSOCIATED WITH BASELINE CONTINUOUS SODIUM HYPOCHLORIDE PRODUCTION

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Vessels:					
Chlorination tank	16,000	7,400	23,400	5,900	34,000
Expansion tank	1,200	300	1,500	380	2,200
Piping and Valves:					
Pipework	3,000	2,000	5,000	1,300	7,300
Ball and globe valves (8)	1,000	250	1,250	320	1,800
Relief valve	1,300	50	1,350	340	2,000
Process Machinery:					
Centrifugal pumps (2)	10,000	4,300	14,300	3,600	21,000
Instrumentation:					
Pressure gauges (3)	600	150	750	190	1,100
Temperature control					
- Controller	1,000	250	1,250	320	1,800
- Sensor	100	25	125	30	180
- Control valve	1,500	380	1,880	470	2,700
pH Control					
- Controller	1,000	250	1,250	320	1,800
- pH detector	4,000	1,000	5,000	1,300	7,300
- Control valve	1,500	380	1,880	470	2,700

(Continued)

TABLE 4-23 (Continued)

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Composition control					
- Controller	1,000	250	1,250	320	1,800
- ORP sensing cell	4,000	1,000	5,000	1,300	7,300
- Control valve	2,000	500	2,500	630	3,600
Flow control					
- Controller	1,000	250	1,250	320	1,800
- Flowmeter	1,300	300	1,600	400	2,300
- Control valve	1,500	380	1,880	470	2,700
Total Costs	53,000	20,000	73,000	18,000	105,000

TABLE 4-24. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 1 CONTINUOUS SODIUM HYPOCHLORIDE PRODUCTION

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Vessels:					
Chlorination tank	16,000	7,400	23,400	5,900	34,000
Expansion tank	1,200	300	1,500	380	2,200
Piping and Valves:					
Pipework	3,800	2,500	6,300	1,600	9,100
Ball and globe valves (8)	1,000	250	1,250	320	1,800
Relief valve	1,300	50	1,350	340	2,000
Process Machinery:					
Centrifugal pumps (2)	10,000	4,300	14,300	3,600	21,000
Instrumentation:					
Pressure gauges (4)	800	200	1,000	250	1,400
Flow indicator	2,000	500	2,500	630	3,600
Local temperature indicator	1,200	300	1,500	380	2,200
Temperature alarm	200	50	250	60	360
Temperature control					
- Controller	1,000	250	1,250	320	1,800
- Sensors (2)	200	50	250	60	360
- Control valve	1,500	380	1,880	470	2,700

(Continued)

TABLE 4-24 (Continued)

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
pH Control					
- Controller	1,000	250	1,250	320	1,800
- pH detector	4,000	1,000	5,000	1,300	7,300
- Control valve	1,500	380	1,880	470	2,700
Composition control					
- Controller	1,000	250	1,250	320	1,800
- ORP sensing cell	4,000	1,000	5,000	1,300	7,300
- Control valve	2,000	500	2,500	630	3,600
Flow control					
- Controller	1,000	250	1,250	320	1,800
- Flowmeter	1,300	300	1,600	400	2,300
- Control valve	1,500	380	1,880	470	2,700
Diking:					
Curbing around reactor	500	130	630	160	910
Enclosure:					
Steel building	4,600	1,200	5,800	1,500	8,300
Total Costs	63,000	22,000	85,000	21,000	[illegible]3,000

TABLE 4-25. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 2 CONTINUOUS SODIUM HYPOCHLORITE PRODUCTION

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Vessels:					
Chlorination tank	16,000	7,400	23,700	5,900	34,000
Expansion tank	1,200	300	1,500	380	2,200
Piping and Valves:					
Pipework	3,800	2,500	6,300	1,600	9,100
Ball and globe valves (8)	1,000	250	1,250	320	1,800
Relief valve	1,300	50	1,350	340	2,000
Process Machinery:					
Centrifugal pumps (2)	10,000	4,300	14,300	3,600	21,000
Instrumentation:					
Level alarm	200	50	250	60	360
Mixing interlock system	1,000	250	1,250	320	1,800
Pressure gauges (4)	800	200	1,000	250	1,400
Flow interlock system	1,000	250	1,250	320	1,800
Flow indicator	2,000	500	2,500	630	3,600
Flow control					
- Controller	1,000	250	1,250	320	1,800
- Flowmeter	1,300	300	1,600	400	2,300
- Control valve	1,500	380	1,880	470	2,700

(Continued)

TABLE 4-25 (Continued)

	Materials Cost	Labor Cost	Direct Costs	Indirect Costs	Capital Cost
			(1986 $)		
Local temp. indicator	1,200	300	1,500	380	2,200
Temperature alarm	200	50	250	60	360
Temperature control					
- Controller	1,000	250	1,250	320	1,800
- Sensors (2)	200	50	250	60	360
- Control valve	1,500	380	1,880	470	2,700
pH Control					
- Controller	1,000	250	1,250	320	1,800
- pH detector	4,000	1,000	5,000	1,300	7,300
- Control valve	1,500	380	1,880	470	2,700
Composition control					
- Controller	1,000	250	1,250	320	1,800
- ORP sensing cell	4,000	1,000	5,000	1,300	7,300
- Control valve	2,000	500	2,500	630	3,600
Diking:					
3 ft retaining wall	900	230	1,130	290	1,600
Enclosure:					
Concrete building	6,100	1,500	7,600	1,900	11,000
Total Costs	67,000	23,000	90,000	23,000	130,000

and valves, process machinery, instrumentation, and procedures and practice. Presentation of the costs in this manner allows for easy comparison of specific items, different levels, and different systems.

Capital Cost--All capital costs presented in this report are shown as total fixed capital costs. Table 4-26 defines the cost elements comprising total fixed capital as it is used here.

The computation of total fixed capital, as shown in Table 4-26, begins with the total direct cost for the system under consideration. This total direct cost is the total direct installed cost of all capital equipment comprising the system. Depending on the specific equipment item involved, the direct capital cost was available or was derived from uninstalled equipment costs by computing costs of installation separately. To obtain the total fixed capital cost, other costs obtained by using factors are added to the total direct costs.

The first group of other cost elements is indirect costs. These include engineering and supervision, construction expenses, and various other expenses, such as administration expenses. These costs are computed by multiplying total direct costs by a factor shown in Table 4-26. The factor is approximate, is obtained from the cost literature, and is based on previous experience with capital projects of a similar nature. Factors can have a range of values and vary according to technology area and for individual technologies within an area. Appropriate factors based on judgement and experience were selected for this report.

When the indirect costs are added to the total direct costs, total bare module cost is obtained. Some additional cost elements, such as contractor's fee and contingency, are calculated by applying and adding appropriate factors to the total bare module cost, as shown in Table 4-26, to obtain the total fixed capital cost.

TABLE 4-26. FORMAT FOR TOTAL FIXED CAPITAL COST

Item No.	Item	Cost
1	Total Material Cost	-
2	Total Labor Cost	-
3	Total Direct Cost	Items 1 + 2
4	Indirect Cost Items (Engineering & Construction Expenses)	0.35 x Item 3[a]
5	Total Bare Module Cost	Items (3 + 4)
6	Contingency	(0.05 x Item 5)[b]
7	Contractor's Fee	0.05 x Item 5
8	Total Fixed Capital Cost	Items (5 + 6 + 7)

[a] For storage facilities, the indirect cost factor is 0.35. For process facilities, the indirect cost factor is 0.25.

[b] For storage facilities, the contingency cost factor is 0.05. For process facilities, the contingency cost factor is 0.10.

Annual Cost--Annual costs are obtained for each equipment item by applying a factor for both capital recovery and for maintenance expenses to the direct cost of each equipment item. Table 4-27 defines the cost elements and the appropriate factors comprising these costs. Additional annual costs are incurred for procedural items such as valve and vessel inspections, for example. The sum of these individual costs equals the total annual cost.

Sources of Information--

Costs presented in this report are derived from cost information in existing published sources and also from recent vendor information. The objective of this effort was to present cost levels for chlorine process and storage facilities using the best costs for available sources. The primary sources of cost information are Peters and Timmerhaus (29), Chemical Engineering (45), and Valle-Riestra (46) supplemented by other sources and references where necessary. Adjustments were made to update all costs to a June 1986 dollar basis. For some equipment items, well-documented costs were not available and they had to be developed from component costs.

Costs in this document reflect the "typical" or "average" representation for specific equipment items. This restricts the use of data in this report to:

- Preliminary estimates used for policy planning;
- Comparison of relative costs of different levels or systems; and
- Approximations of costs that might be incurred for a specific application.

The costs in this report are considered to be "order of magnitude" with a ±50 percent margin. This is because costs are based on preliminary estimates and many are updated from literature sources. Large departures from the

TABLE 4-27. FORMAT FOR TOTAL ANNUAL COST

Item No.	Item	Cost
1	Total Direct Cost	-
2	Capital Recovery on Equipment Items	0.163 x Item 1
3	Maintenance Expense on Equipment Items	0.01 x Item 1
4	Total Procedural Items	-
5	Total Annual Cost	Items (2 + 3 + 4)

design basis of a particular system presented in this manual or the advent of a different technology might cause the system cost to vary more than this. If used as intended, however, this document will provide a reasonable source of preliminary cost information for the facilities covered.

When comparing costs in this manual to those from other references, the user should be sure the design bases are comparable and that the capital and annual costs as defined here are the same.

Cost Updating--

All costs in this report are expressed in June 1986 dollars. Costs reported in the literature were updated using cost indices for materials and labor.

Costs expressed in base-year dollars may be adjusted to dollars for another year by applying cost indices as shown in the following equation:

$$\text{new base-year cost} = \text{old base-year cost} \times \frac{\text{new base year index}}{\text{old base year index}}$$

The Chemical Engineering (CE) Plant Cost Index was used to update costs for this report. For June 1986, the index is 316.3.

Equipment Costs--

Most of the equipment costs presented in this manual were obtained directly from literature sources of vendor information and correspond to a specific design standard. Special cost estimating techniques, however, were used in determining the costs associated with vessels, piping systems, scrubbers, diking, and enclosures. The techniques used are presented in the following subsections of this manual.

Vessels--The total purchased cost for a vessel, as dollars per pound of weight of fabricated unit free-on-board freight basis (f.o.b.), with carbon

steel as the basis (January 1979 dollars) were determined using the following equation from Peters and Timmerhaus (29):

$$\text{Cost} = [50(\text{Weight of Vessel in Pounds})^{-0.34}][\text{Weight of Vessel in Pounds}]$$

The vessel weight is determined using appropriate design equations, as given by Peters and Timmerhaus (29), that allow for wall thickness adjustments for corrosion allowances, for example. The vessel weight is increased by a factor of 0.15 for horizontal vessels and 0.20 for vertical vessels to account for the added weight of nozzles, manholes, and skirts or saddles. Appropriate factors are applied for different materials of construction as given in Peters and Timmerhaus (29). Vessel costs are updated using cost factors. Finally a shipping cost amounting to 10 percent of the purchased cost is added to obtain the delivered equipment cost.

Piping--Piping costs were obtained using cost information and data presented by Yamartino (33). A simplified approach is used in which it is assumed that a certain length of piping containing a given number of valves, flanges, and fittings is contained in the storage or process facility. The data presented by Yamartino (33) permit cost determinations for various lengths, sizes, and types of piping systems. Using these factors, a representative estimate can be obtained for each of the storage and process facilities.

Diking--Diking costs were estimated using Mean's Manual (35) for reinforced concrete walls. The following assumptions were made to determine the costs. The dike contains the entire contents of a tank in the event of a leak or release. Two dike sizes are possible: a three-foot high dike, six-inches thick and a top-of-tank height dike ten inches thick. The tanks are raised off the ground and are not volumetrically included in the volume enclosed by the diking. These assumptions facilitate cost determination for any size diking system.

Enclosures--Enclosure costs were estimated using Mean's Manual (35) for both reinforced concrete and steel-walled buildings. The buildings are assumed to enclose the same area and volume as the top-of-tank height dikes. The concrete building is ten-inches thick with a 26-gauge steel roof and a metal door. The steel building has 26 gauge roofing and siding and metal door. The cost of a ventilation system was determined using a typical 1,000 scfm unit and doubling the cost to account for duct work and requirements for the safe enclosure of hazardous chemicals.

Scrubbers--Scrubber costs were estimated using the following equation from the Gard (41) manual for spray towers based on the actual cubic feet per minute of flow at a chamber velocity of 600 feet/minute.

$$\text{Costs} = 0.235 \times (\text{ACFM} + 43{,}000)$$

A release rate of 10,000 ft^3/minute was assumed for the storage vessel systems and an appropriate rate was determined for process system based on the quantity of hazardous chemicals present in the system at any one time. For the chlorine bleach reactor system, a release rate of 10,000 ft^3/minute was assumed. In addition to the spray tower, the costs also include pumps and a storage tank for the scrubbing medium. The costs presented are updated to June 1986 dollars.

Installation Factors--

Installation costs were developed for all equipment items included in both the process and storage systems. The costs include both the material and labor costs for installation of a particular piece of equipment. The costs were obtained directly from literature sources and vendor information or indirectly by assuming a certain percentage of the purchased equipment cost through the use of estimating factors obtained from Peters and Timmerhaus (29) and Valle-Riestra (46). Table 4-28 lists the cost factors used or the reference from which the cost was obtained directly. Many of the costs obtained from the literature were updated to June 1986 dollars using a 10 percent per

TABLE 4-28. FORMAT FOR INSTALLATION COSTS

Equipment Item	Factor or Reference
Vessels:	
Storage Tank	0.45
Expansion Tank	0.25
Piping and Valves:	
Pipework	Ref. 21
Expansion Loop	Ref. 18
Reduced Pressure Device	Ref. 18
Check Valves	Ref. 18
Gate Valves	Ref. 18
Ball Valves	Ref. 18
Excess Flow Valves	Ref. 18
Angle Valves	Ref. 23
Relief Valves	Ref. 18
Rupture Disks	Ref. 18
Process Machinery:	
Centrifugal Pump	0.43
Gear Pump	0.43
Instrumentation:	
All Instrumentation Items	0.25
Enclosures:	Ref. 23
Diking:	Ref. 23
Scrubbers:	0.45

year rate of increase for labor and cost indices for materials associated with installation.

SECTION 5

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APPENDIX A
GLOSSARY

This glossary defines selected terms used in the text of this manual which might be unfamiliar to some users or which might be used differently by different authors.

Accidental release: The unintentional spilling, leaking, pumping, purging, emitting, emptying, discharging, escaping, dumping, or disposing of a toxic material into the environment in a manner that is not in compliance with a plant's federal, state, or local environmental permits and/or results in toxic concentrations in the air that are a potential health threat to the surrounding community.

Assessment: The process whereby the hazards which have been identified are evaluated in order to provide an estimate for the level of risk.

Cavitation: The formation and collapse of vapor bubbles in a flowing liquid. Specifically the formation and collapse of vapor cavities in a pump when there is sufficient resistance to flow at the inlet side.

Containment/control: A system to which toxic emissions from safety relief discharges are routed to be controlled. A caustic scrubber and/or flare can be containment/control devices. These systems may serve the dual function of destructing continuous process exhaust gas emissions.

Creep failure: Failure of a piece of metal as a result of creep. Creep is time dependent deformation as a result of stress. Metals will deform when exposed to stress. High levels of stress can result in rapid deformation and rapid failure. Lower levels of stress can result in slow deformation and protracted failure.

Deadheading: Closing or nearly closing or blocking the discharge outlet or piping of an operating pump or compressor.

Facility: A location at which a process or set of processes are used to produce, refine or repackage chemicals, or a location where a large enough inventory of chemicals are stored so that a significant accidental release of a toxic chemical is possible.

Hazard: A source of danger. The potential for death, injury or other forms of damage to life and property.

Hygroscopic: Readily absorbing and retaining moisture, usually in reference to readily absorbing moisture from the air.

Identification: The recognition of a situation, its causes and consequences relating to a defined potential, e.g. Hazard Identification.

Mild steel: Carbon steel containing a maximum of about 0.25% carbon. Mild steel is satisfactory for use where severe corrodants are not encountered or where protective coatings can be used to prevent or reduce corrosion rates to acceptable levels.

Mitigation: Any measure taken to reduce the severity of the adverse effects associated with the accidental release of a hazardous chemical.

Passivation film: A layer of oxide or other chemical compound of a metal on its surface that acts as a protective barrier against corrosion or further chemical reaction.

Plant: A location at which a process or set of processes are used to produce, refine, or repackage, chemicals.

Prevention: Design and operating measures applied to a process to ensure that primary containment of toxic chemicals is maintained. Primary containment means confinement of toxic chemicals within the equipment intended for normal operating conditions.

Primary Containment: The containment provided by the piping, vessels and machinery used in a facility for handling chemicals under normal operating conditions.

Probability/potential: A measure, either qualitative or quantitative, that an event will occur within some unit of time.

Process: The sequence of physical and chemical operations for the production, refining, repackaging or storage of chemicals.

Process machinery: Process equipment, such as pumps, compressors, heaters, or agitators, that would not be categorized as piping or vessels.

Protection: Measures taken to capture or destroy a toxic chemical that has breached primary containment, but before an uncontrolled release to the environment has occurred.

Qualitative Evaluation: Assessing the risk of an accidental release at a facility in relative terms; the end result of the assessment being a verbal description of the risk.

Quantitative Evaluation: Assessing the risk of an accidental release at a facility in numerical terms; the end result of the assessment being some type of number reflects risk, such as faults per year or mean time between failure.

Reactivity: The ability of one chemical to undergo a chemical reaction with another chemical. Reactivity of one chemical is always measured in reference to the potential for reaction with itself or with another chemical. A chemical is sometimes said to be "reactive", or have high "reactivity", without reference to another chemical. Usually this means that the chemical has the ability to react with common materials such as water, or common materials of construction such as carbon steel.

Redundancy: For control systems, redundancy is the presence of a second piece of control equipment where only one would be required. The second piece of equipment is installed to act as a backup in the event that the primary piece of equipment fails. Redundant equipment can be installed to backup all or selected portions of a control system.

Risk: The probability that a hazard may be realized at any specified level in a given span of time.

Secondary Containment: Process equipment specifically designed to contain material that has breached primary containment before the material is released to the environment and becomes an accidental release. A vent duct and scrubber that are attached to the outlet of a pressure relief device are examples of secondary containment.

Toxicity: A measure of the adverse health effects of exposure to a chemical.

APPENDIX B

TABLE B-1. METRIC (SI) CONVERSION FACTORS

Quantity	To Convert From	To	Multiply By
Length:	in	cm	2.54
	ft	m	0.3048
Area:	in^2	cm^2	6.4516
	ft^2	m^2	0.0929
Volume:	in^3	cm^3	16.39
	ft^3	m^3	0.0283
	gal	m^3	0.0038
Mass (weight):	lb	kg	0.4536
	short ton (ton)	Mg	0.9072
	short ton (ton)	metric ton (t)	0.9072
Pressure:	atm	kPa	101.3
	mm Hg	kPa	0.133
	psia	kPa	6.895
	psig	kPa*	(psig)+14.696)x(6.895)
Temperature:	°F	°C*	(5/9)x(°F-32)
	°C	K*	°C+273.15
Caloric Value; Enthalpy:	Btu/lb	kJ/kg	2.326
	Btu/lbmol	kJ/kgmol	2.326
	kcal/gmol	kJ/kgmol	4.184
Specific-Heat Capacity:	Btu/lb-°F	kJ/kg-°C	4.1868
Density:	lb/ft^3	kg/m^3	16.02
	lb/gal	kg/m^3	119.8
Concentration:	oz/gal	kg/m^3	
	quarts/gal	cm^3/m^3	25,000
Flowrate:	gal/min	m^3/min	0.0038
	gal/day	m^3/day	0.0038
	ft^3/min	m^3/min	0.0283
Velocity:	ft/min	m/min	0.3048
	ft/sec	m/sec	0.3048
Viscosity:	centipoise (CP)	kg/m-s	0.001

*Calculate as indicated